TECHNICAL BULLETIN No. 744 • MARCH 1941

Life History of the Sugar-Beet Wireworm in Southern California

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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By M. W. STONE, *assistant entomologist, Division of Truck Crop and Garden Insect Investigations, Bureau of Entomology and Plant Quarantine* [1a]

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INTRODUCTION

The sugar-beet wireworm (*Limonius californicus* (Mann.)) [2] is the most important soil-inhabiting insect pest of sugar beets and lima beans on the Pacific coast. Its destructiveness is also well known to growers of potatoes, vegetables, alfalfa, and bulbs. Because of the variety of crops attacked and the nature of the injury the losses caused by this species are difficult of estimation. Injury to sprouting seeds usually results in large losses through a reduction in stand, or involves the added expense of replanting. Growing plants may be killed or badly injured and their growth stunted. Often potatoes or root crops are so badly damaged that they are rendered unmarketable or require grading before being fit for marketing. In 1919, in Ventura County, Calif., alone, out of over 90,000 acres planted to lima beans

[1] Received for publication January 18, 1940.

[1a] The writer expresses his appreciation to Roy E. Campbell, entomologist in charge of the truck crop and garden insect laboratory of this Bureau at Alhambra, Calif., under whose immediate supervision these biological studies were conducted, for helpful suggestions, criticisms, and assistance during the investigation and in the preparation of the manuscript. Appreciation is also extended to J. C. Elmore of the same laboratory for the assistance given in photographing the various insect stages. The writer is also greatly indebted to A. F. Howland, K. D. Sloop, and C. Henne for their valuable aid in carrying out the life-history investigations. C. S. Guy contributed materially by drawing the graphs and assisting in the field work. Thanks are due to Vernon L. Woolley of Ventura, Calif., for making collections of adults under malva traps in 1932, 1933, and 1934.

[2] Order Coleoptera, family Elateridae.

over 20,000 acres were estimated by the agricultural commissioner to have been damaged to the extent of from 10 to 100 percent, the loss amounting to $500,000. In Los Angeles, Orange, and Santa Barbara Counties the damage annually ranges from 10 to 50 percent.

In 1914 Graf (*4*),[3] of the Bureau of Entomology, published a preliminary report covering his investigations of the sugar-beet wireworm in southern California during the period 1909–12. The project was resumed by the Bureau in 1924, the investigations at this time being concerned primarily with the use of fumigants and baits in an effort to obtain a practical control. In that year Campbell (*1*) published a report on the use of calcium cyanide as a soil fumigant for wireworms, and in 1926 (*2*) his paper on concentrating wireworms by baits before fumigating the soil with calcium cyanide. This method of control with calcium cyanide has been found the most practical so far devised and is being widely used for controlling wireworms in the truck-crop-growing areas of California.

Without a thorough knowledge of the life history of this species, however, no definite statement could be made regarding the length of time after treatment that protection was afforded. In addition, the high cost of production together with the drop in the prices of agricultural products necessitated further reduction in the cost of control. For these reasons the Alhambra laboratory of the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture undertook a study of the life history, under southern California conditions, of the sugar-beet wireworm, in an attempt to reveal any unusual features in its life history that might be taken advantage of in combating this pest at a lower cost. These studies were, of necessity, performed principally in the laboratory or in outdoor cages, supplemented by such observations on the developmental stages in the field as were possible in view of the habits of the species under consideration. A report of the results of these investigations from the beginning of the studies in 1929 until the close of the season of 1934–35 is presented in this bulletin.

DISTRIBUTION

According to Van Dyke (*9*) *Limonius californicus* is distributed throughout the irrigated areas of the Pacific Coast States. In California it is especially abundant in Los Angeles, Ventura, Orange, San Bernardino, Riverside, Santa Barbara, San Diego, and Sacramento Counties. Graf (*4*) reports that the insect also occurs in Inyo, Monterey, Alameda, Marin, Eldorado, and Lake Counties. Additional records obtained from specimens in the collection of the California Academy of Sciences at San Francisco include Modoc, San Joaquin, Mendocino, Contra Costa, San Mateo, Napa, Santa Cruz, San Luis Obispo, Tulare, and Calaveras Counties (fig. 1).

The subspecies *occidentalis* Cand. is more prevalent in the inland sections of California and farther to the north. Specimens in Van Dyke's collection have the following locality labels: Los Angeles, Palm Springs, Tejon Canyon, and Paso Robles; and there are also some from Sonoma, Placer, Trinity, and Shasta Counties.

[3] Italic numbers in parentheses refer to Literature Cited, p. 87.

No extensive scouting to determine the complete distribution was possible, so the actual infested area may comprise many counties other than those mentioned above.

NATURE OF INJURY

The injury to most crops by *Limonius californicus* is from attacks of the larvae on the germinating seed soon after it is planted (fig. 2),

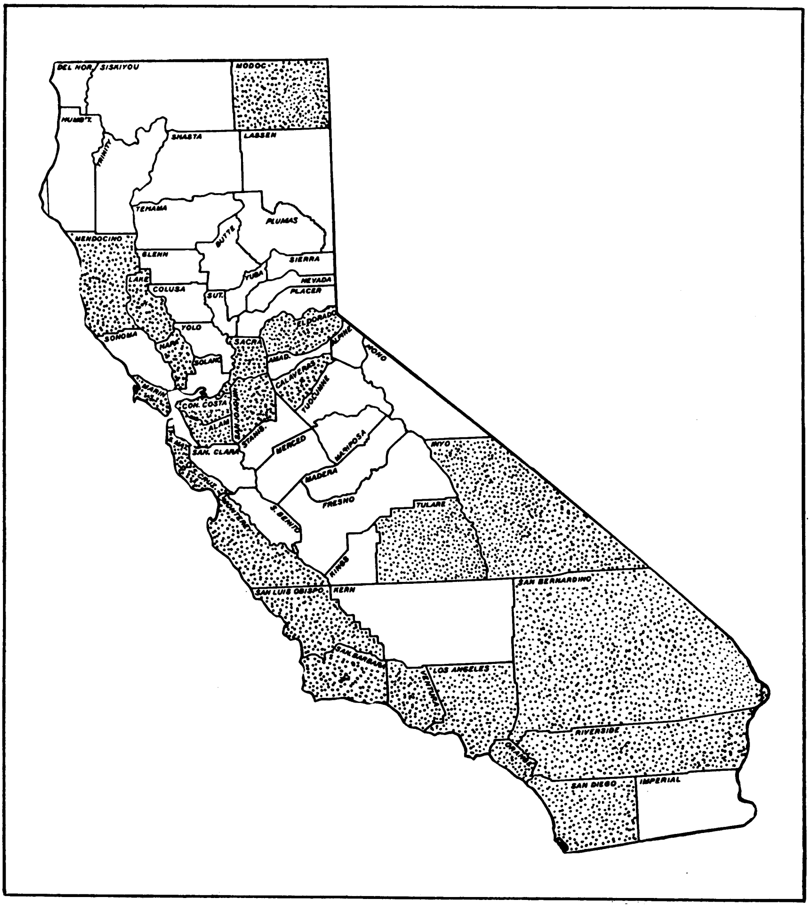

FIGURE 1.—Distribution of the sugar-beet wireworm in California. The counties from which the insect has been reported are shaded.

or to the young plant shortly after the seed has sprouted (fig. 3). The larvae may eat the entire contents of the seed, leaving only the empty husks, or destroy only that portion containing the germ before moving on to another seed. Observations have shown that injury to seed is especially severe where germination has been retarded by unfavorable soil conditions. The stems of growing plants are burrowed into below the surface, leaving only fragments of the stem to support the top

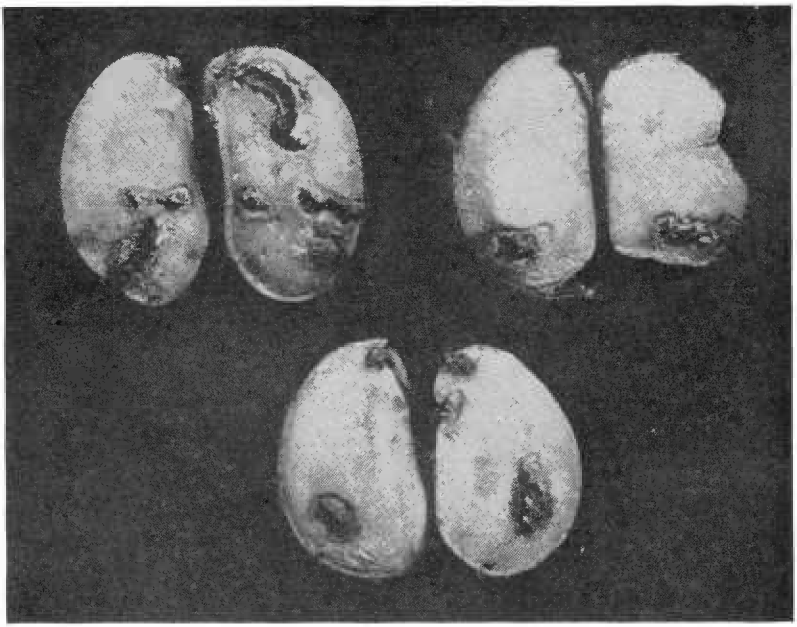

FIGURE 2.—Germinating lima beans injured by the sugar-beet wireworm.

FIGURE 3.—Lima bean plants: *A*, Injured by a sugar-beet wireworm that burrowed into the stem; *B*, uninjured.

(fig. 4). Occasionally plants that are well rooted will recover from a light attack, but in most cases the plant is killed outright. While lighter infestations are characterized by a few missing plants here and there over the field, it is common in cases of severe infestation to find spots ranging in size from a few square feet to an acre or more with all plants killed (fig. 5).

Potatoes are damaged mainly in two ways. (1) The planted seed pieces are burrowed into and injured, sometimes to an extent that necessitates replanting; and (2) feeding punctures, or "stings," in the mature tuber cause them to be sorted into a lower grade, or classified as culls (fig. 6). Damage to sugar beets is to the young plants, which may be killed outright (fig. 7) or the taproot cut off so that an inferior beet develops (fig. 8). Injury to bulbs begins as soon as they are planted, and often is severe enough to prevent proper growth. The larvae also feed on lima beans and on the stems and roots of lettuce, cauliflower, tomato, corn, alfalfa, wheat, and melons, killing or stunting the plants.

FIGURE 4.—The lima bean plant in the center is wilting after an attack by a sugar-beet wireworm.

In southern California, injury to crops may begin early in February and continue throughout the spring and late into June. Where irrigation is practiced, along the cool coastal areas, severe injury may be expected even throughout the summer. In unirrigated districts high surface temperatures accompanied by the drying out of the topsoil cause the larvae to descend to lower depths, where apparently there is little feeding. With lower temperatures early in the fall, they again migrate toward the surface to resume feeding. Damage usually ceases about the middle of October, as then soil temperatures have dropped sufficiently to cause inactivity.

This species seems to show a preference for, and is usually more injurious in, soils ranging from sandy to heavy loam. The degree of acidity or alkalinity of the soil does not appear to be a factor in the activities of this species. Experiments conducted in 1932 showed that the rate of hatching and the activity of newly hatched larvae were not retarded in the least in soils with a hydrogen-ion concentration as low as 3.5. Furthermore, it was found that when newly hatched larvae were confined in outdoor cages in soils ranging from pH 4.0 to pH 5.0 for a period of 9 months, they actually increased in weight

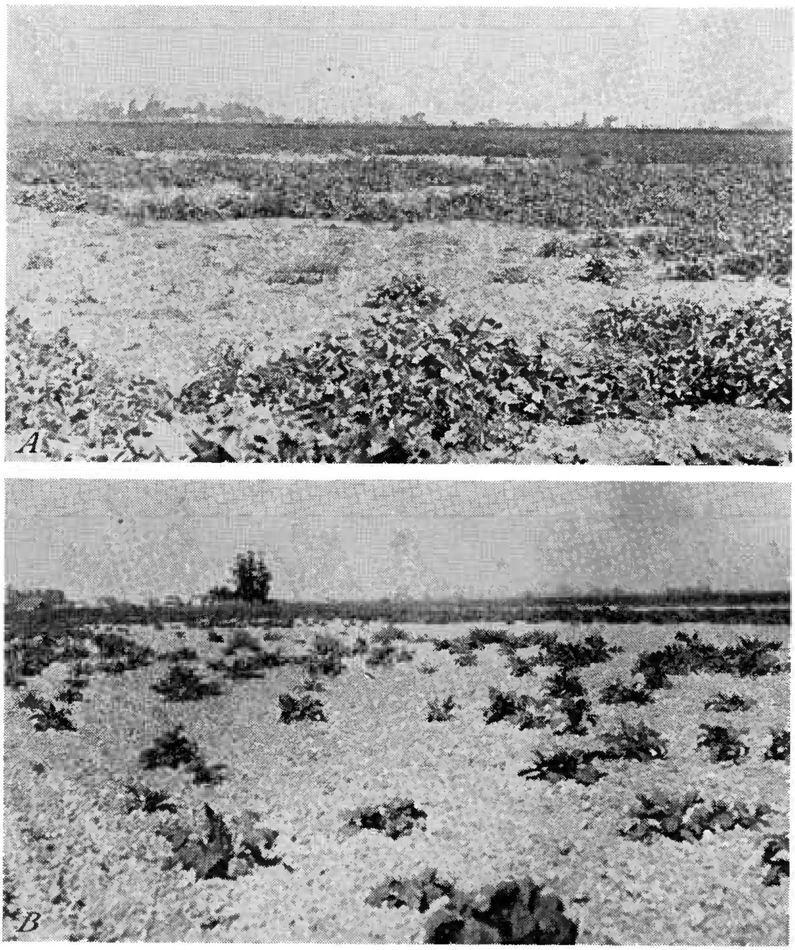

FIGURE 5.—Lima bean field (A) and sugar-beet field (B) showing large areas where the plants have been destroyed by the feeding of the sugar-beet wireworm.

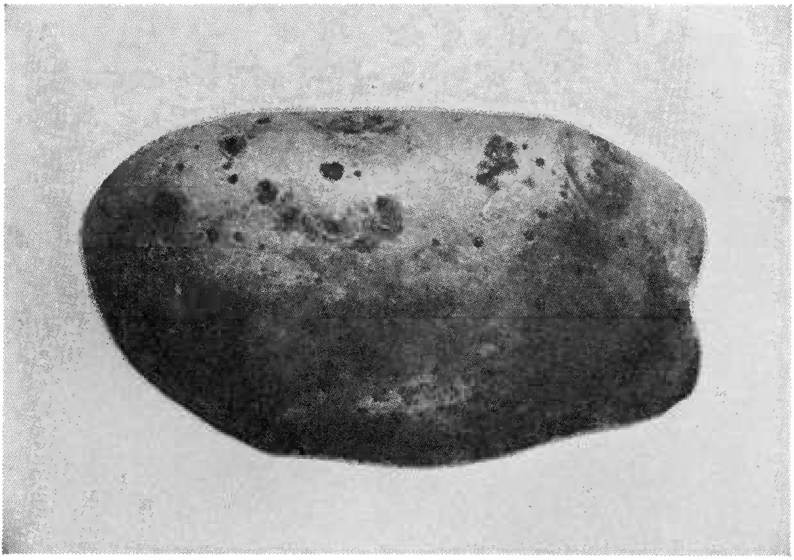

FIGURE 6.—Feeding punctures of the sugar-beet wireworm on a potato.

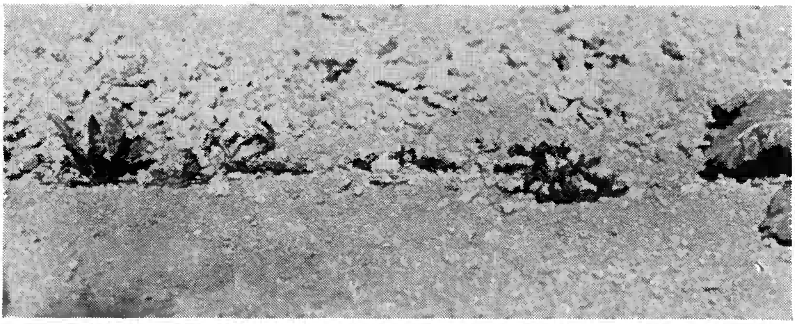

FIGURE 7.—Young sugar-beet plants killed by the severing of the taproot by the sugar-beet wireworm.

as rapidly as those confined in neutral soils. Field experiments in which sulfur (*3*) was used in quantities ranging from 300 to 10,000 pounds per acre proved effective in lowering the hydrogen-ion concentration of the soil but failed to reduce the larval population and the damage to the planted potatoes. McDougall (*6, p. 716*), in a survey of wireworm-infested fields in Queensland, found that larvae of *Lacon variabilis* Cand. inhabited soil ranging from pH 3.9 to pH 5.8

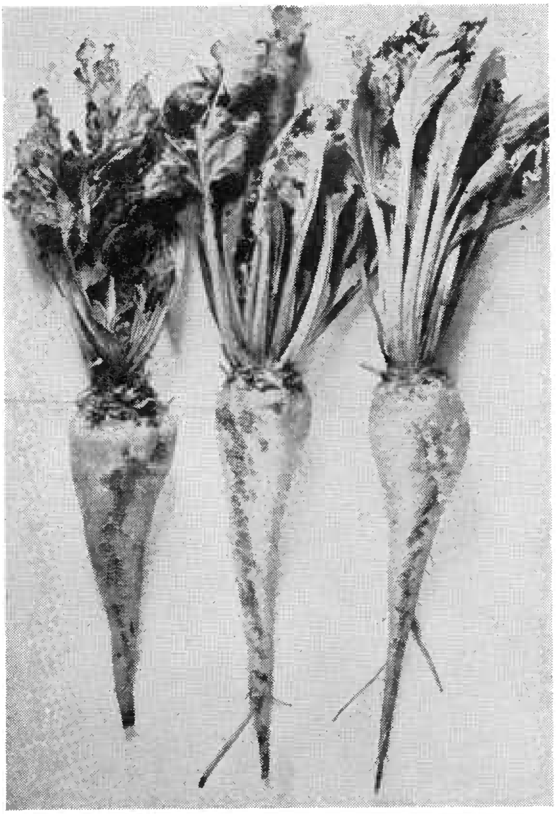

FIGURE 8.—Typical sugar-beet wireworm injury to young beets (Graf).

and that parts of any field inhabited by this species were usually more acid than the remainder of the field.

DISSEMINATION

Females as well as males are strong, vigorous fliers, and are especially active on warm, clear days. The maximum distance which individual beetles can fly is largely determined by the temperature, the wind velocity, and whether or not the field of flight is covered by vegetation. Marked females, which had been liberated on a warm day in a fallowed field near El Monte, flew toward a field of mustard and were recovered there a few minutes later about 100 yards from the point of liberation. Adults normally fly with the wind, but they can fly with little diffi-

culty against a light breeze. During strong winds, such as prevail along the coast late in the afternoon, adults cease flying and crawl to the base of plants or under clods for protection.

Field and oviposition studies show that normal activity for this species occurs when the soil-surface temperature ranges between 75° and 80° F. When the surface temperature drops below 70°, less flying occurs, and below 65° very little activity has been noted. Adults were scarce during cloudy weather and on days following rains. The beginning of their activity each day is of course governed by temperature. Very few beetles were collected before 9 a. m. or after 4 p. m.

Effect of Crops on Dispersion

Observations in the field have shown that adults are attracted to alfalfa or green cover crops because of the lower temperatures prevailing there and for the shelter which such crops afford. Quite frequently temperatures on the soil surface in the sun have reached as high as 105° F. in February and 125° in March, while at the same time the temperature on the soil surface in alfalfa fields was from 20° to 30° lower. Studies in 1932 showed that 60 and 20 percent of a group of males and females, respectively, which had been resting on the sides of their oviposition cages, succumbed on February 27 when the temperature on the soil surface in the sun remained at 105° for one-half hour. In fallowed fields, therefore, when temperatures are in excess of 90° on the surface it is natural to expect an immediate dispersal to fields containing alfalfa or cover crops. Additional proof of this was demonstrated when liberating marked individuals of both sexes on an extremely hot day near a group of malva traps.[4] All the beetles took flight immediately in the direction of the piles of malva, where they were recovered a few minutes later, none remaining on the surface or under the clods where liberated. That oviposition occurs in alfalfa fields is shown by comparative population counts made in December 1933 in plots of corn and alfalfa in which adults had been confined the year previous. The count in the alfalfa plot showed an average of 24 larvae as compared with 10.6 larvae per square foot in the corn plot.

On the basis of this evidence, the importance of alfalfa fields as breeding areas for this species cannot be underestimated, when control measures are attempted.

Food Not a Factor in Dispersion

Observations by Graf (*4*) have shown that adults favor old beet roots for food and feed lightly on alfalfa, Johnson grass, and wild beet roots. In addition, the writer has observed feeding punctures on slices of potatoes and large numbers of adults on rhubarb flowers, apparently feeding on the pollen. During the 4-year period that oviposition studies were conducted no food was provided the adult pairs in their respective containers. In most cases these specimens were alive after all adults in the field had died. Apparently no relationship between food and dispersal exists, and, as Graf has stated, the feeding of the adults, from an economic point of view, may be disregarded.

[4] These traps consisted of loose piles of malva (*Malva parviflora* L.) 3 feet in diameter, placed 100 feet apart in shallow excavations.

DESCRIPTIONS OF THE STAGES

The Adult

(Fig. 9, *A*)

The original description by Mannerheim (*7, p. 238*) appeared in 1843. Van Dyke (*9, p. 340*) redescribed the insect in 1932 in a key as follows:

Clypeal margin not distinctly notched and depressed at middle, head and pronotum more or less aeneous, anterior pronotal margin but slightly lobed at middle,

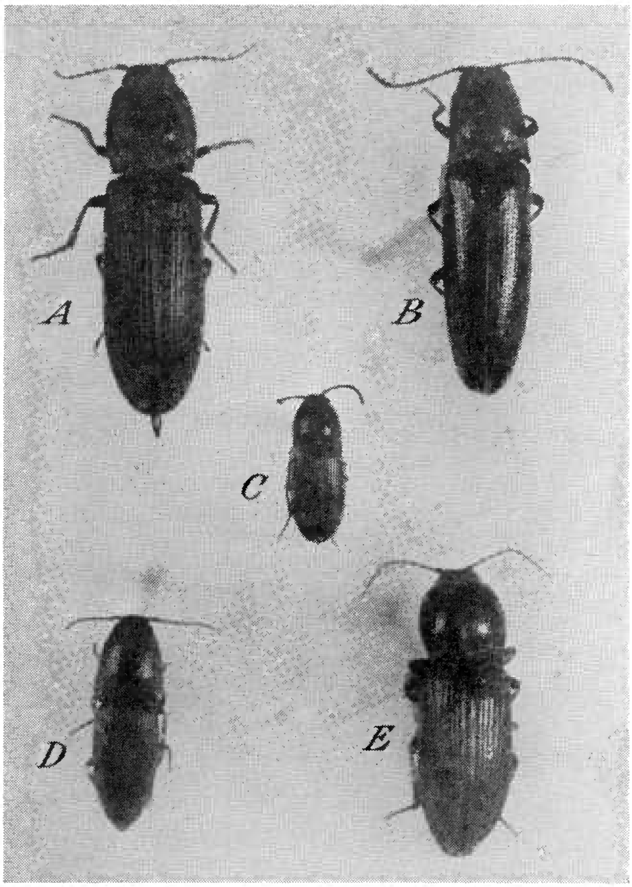

Figure 9.—Elaterids commonly found in fields in southern California, × 4: *A*, *Limonius californicus; B*, *Melanotus longulus; C*, *Anchastus cinereipennis; D*, *Aeoleus livens;* and *E*, *Cardiophorus tenebrosus.*

elytral intervals not carinate apically; species in general robust and not markedly narrowed either in front or behind..38

38. Species in general black with head and pronotum aeneous, elytra sometimes brown, distinctly pilose; second antennal segment slightly longer than broad, third still longer and subcylindrical, together longer than fourth especially in the female; elytra finely striato-punctate, intervals broad, flat and distinctly and irregularly punctured; length 8.5–12 mm. Pacific States...*californicus* (Mann.)

According to Van Dyke there are three color phases of this species, the black or typical phase, the brownish or reddish phase, and the

dark orange phase or subspecies *occidentalis*. The last occurs farther north and more inland in the hotter sections. The examination of large numbers of adults taken under malva traps in Ventura County over a period of 3 years showed that approximately 4 percent of the beetles collected were reddish and the remainder brownish to black. Occasionally a few of the brownish or reddish adults were collected in Orange and Los Angeles Counties, but the majority were dull brown or black. The adults reared and reported herein were entirely of the black or typical phase of *Limonius californicus*.

The Egg [5]

The egg is ellipto-cylindrical in shape. Both ends are broadly rounded and resemble each other. Measurement of 30 eggs gave an average length of 0.69 mm. and an average width of 0.5 mm. The length varied between 0.63 and 0.735 mm. and the width between 0.473 and 0.53 mm.

The Larva

(Fig. 10, *B*)

The nearly mature larva * * * is subcylindrical in shape and shiny, waxy yellowish-brown in color. The segments are very minutely and sparsely punctate. The head and venter are flattened dorsally and darker in color. There is a light dorsal stripe on the posterior end of each segment with the exception of the venter.

The head is depressed and considerably narrower in front. The mandibles are strong, notched, deep brown in color, changing to black at the tip.

The first thoracic segment is broad and long, being about equal in length to the venter. The other thoracic segments are short, being about equal in length to the first two abdominal segments. The remaining abdominal segments are a little longer and quite similar. The legs are short and armed with heavy, short brown spines.

The abdominal segments are slightly constricted where they join one another. There are from two to four hairs on the lateral side of each segment. The spiracles are brown, conspicuous, and are situated in a poorly defined, light lateral stripe. They are slightly nearer the anterior end of the segment.

The venter is depressed dorsally, with raised edges. It is sparsely hairy around the edge. The caudal notch has a small tooth on each side pointing slightly upward and backward. The margin of the notch varies from deep brown to black.

The average length of the mature larva is from 18 to 21 mm., and the width is from 2.5 to 3 mm.

The Pupa

(Fig. 11)

When first formed the pupa is opaque white, but after a time the eyes show through as pale, dusky, blue spots. About this time the thoracic segments become a pale waxy yellow, but no other changes take place until shortly before emergence.

The pupa very much resembles the adult beetle in shape, except that the abdomen is slightly longer in the pupal stage. The head is bent forward slightly, and each anterior angle is armed with a long, heavy spine, which tapers regularly to a point. The mouth parts are conspicuous. The antennæ are laid along the margin of the head on the ventral side, and their tips are behind the tibiæ of the second pair of legs. On the underside of the head and near the prothorax are two short, heavy spines. There are also two short, stout spines on the dorsal side of the head near the posterior angles.

The case covering the springing apparatus is plainly visible between the anterior coxæ. The leg cases are folded similarly to those of other Elateridæ. All of the posterior pair, excepting the tarsi, are covered by the wing cases, which are curved around and almost meet on the ventral side, at the distal end of the third abdominal segment.

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[5] Description of egg, larva, and pupa quoted from Graf (*4, pp. 14–16*).

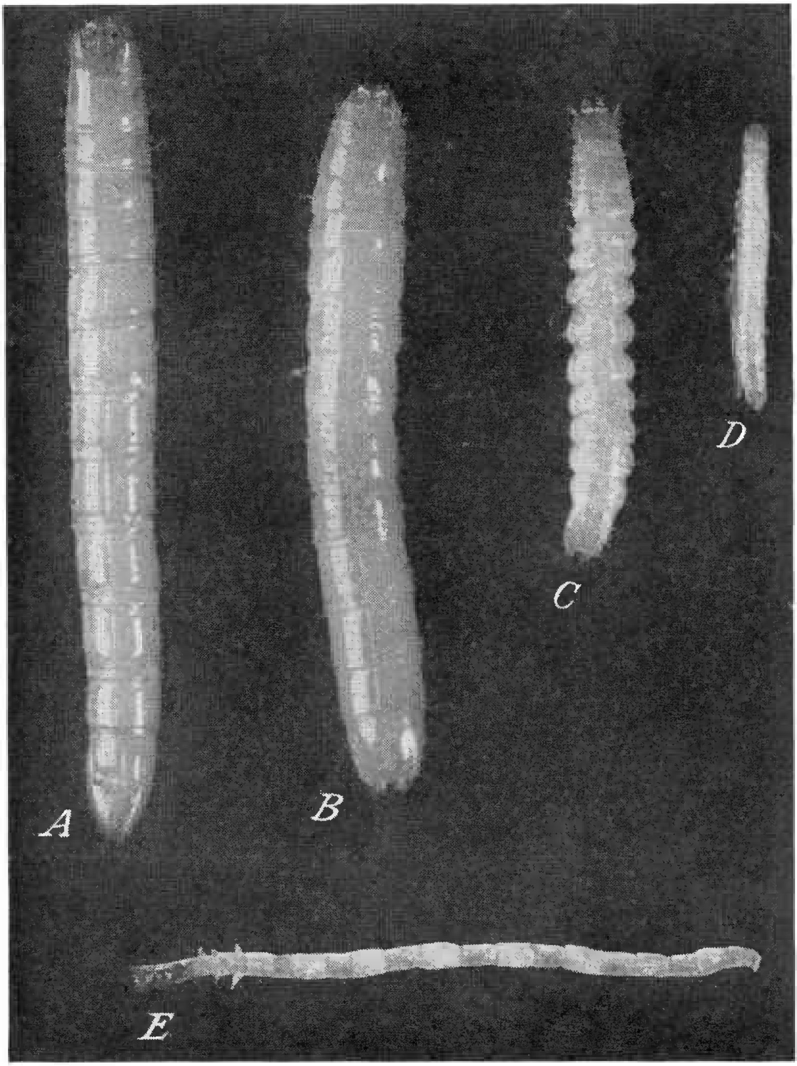

FIGURE 10.—Elaterid larvae found in fields in southern California, × 7: *A*, *Melanotus longulus; B*, *Limonius californicus; C*, *Aeoleus livens; D*, *Anchastus cinereipennis; E*, *Cardiophorus tenebrosus.*

The abdomen is contracted sharply at the seventh segment, so that the eighth segment is only a little more than half as wide as the anterior end of the seventh.

The anal segment bears two long, heavy spines on its posterior angles. These spines are slightly divergent, are pitted, and the distal half of each is brown, changing to black at the tip.

The pupæ vary greatly in size. Measurements taken from several individuals give an average length of 11.5 mm. and a width of 3.6 mm.

ELATERIDS[6] ASSOCIATED WITH THE SUGAR-BEET WIREWORM

Although *Limonius californicus* is the predominant wireworm in southern California fields, several other destructive elaterids are frequently encountered (figs. 9 and 10). The larvae of the different species are readily separated by the shape of their anal segments, as is shown in figure 12. Probably the most important of these is *Melanotus longulus* (Lec.) (figs. 9, *B;* 10, *A;* 12, *B*), an elaterid largely restricted in its distribution to western Ventura County, but which also occurs in Los Angeles County, in the vicinity of El Monte. The

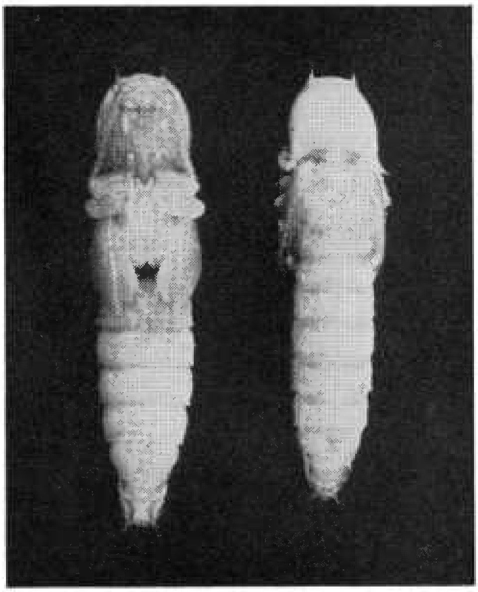

FIGURE 11.—Pupa of *Limonius californicus*, ventral and dorsal views. × 4.

adults (fig. 9, *B*), which are easily distinguishable by their shiny black elytra and quick movements when disturbed, are active from the 1st of April until June. Males of this species average 10 mm. and the females 11 mm. in length. The larvae are reddish brown, cylindrical, and much more active than *L. californicus*.

Aeoleus livens (Lec.) (figs. 9, *D;* 10, *C;* 12, *D*), reddish in color, and with large dark spots on the thorax and elytra (fig. 9, *D*), is very common from the middle of February until May in all areas inhabited by *Limonius californicus*. The male averages 6.5 mm. in length and the female 8.5 mm. The larva (fig. 10 *C*), waxy white with a brownish head and thorax, has a more flattened body than the other species encountered.

Anchastus cinereipennis (Esch.) (figs. 9, *C;* 10, *D;* 12, *C*) is the small, light to dark-brown, and very active elaterid which appears early in March. The adults range from 4 to 6 mm. in length. The larva is

[6] Determinations by E. C. Van Dyke.

pale yellow with brown head and reaches a length of 12 mm. when mature.

Cardiophorus tenebrosus Lec. (figs. 9, *E;* 10, *E;* 12, *E*) is black, 7 to 9 mm. in length, and common in alfalfa fields during February, March, and April. The larva, whitish with a brown head, is extremely delicate and difficult to rear. If picked up in the center by forceps, both ends of this species hang down in a stringlike fashion.

Limonius canus Lec. and *L. infuscatus* Mots. are also known to be present in southern California.

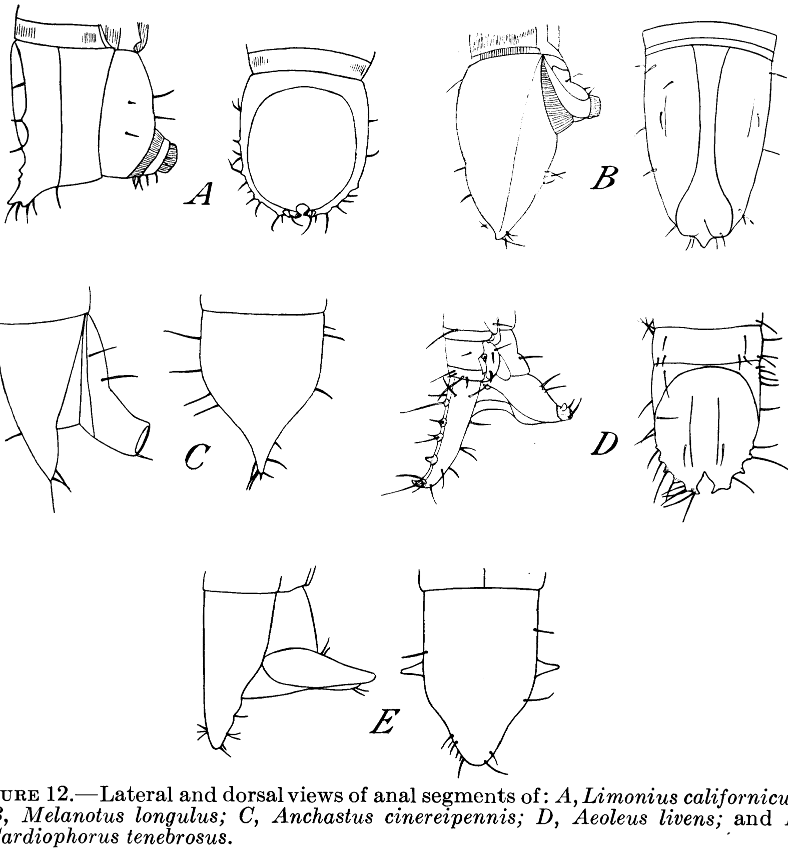

FIGURE 12.—Lateral and dorsal views of anal segments of: *A, Limonius californicus; B, Melanotus longulus; C, Anchastus cinereipennis; D, Aeoleus livens;* and *E, Cardiophorus tenebrosus.*

LIFE-HISTORY STUDIES

TEMPERATURE RECORDS

Air temperatures were obtained by means of a thermograph placed in a Weather Bureau shelter 3½ feet above the soil surface. A thermograph was also used for recording the temperatures in the basement of the insectary. Soil temperatures were measured at the 4-, 8-, and 12-inch depths, weekly recording thermometers being used. The mean monthly air, basement, and soil temperatures for the period from June 1930 to December 1934 are shown in table 1 and figure 13.

TABLE 1.—*Mean monthly soil, basement, and air*[1] *temperatures (°F.) Alhambra, Calif., 1930–34*

Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1930													
Soil, 4-inch depth	------	------	------	------	------	73.3	73.7	78.5	73.2	68.6	59.5	49.9	------
Soil, 8-inch depth	------	------	------	------	------	72.1	74.2	75.1	71.5	64.7	57.8	48.9	------
Soil, 12-inch depth	------	------	------	------	------	70.0	76.6	78.3	74.8	66.6	58.3	47.4	------
Basement	------	------	------	------	------	67.8	70.8	73.2	68.7	65.5	63.2	58.6	------
Air	------	------	------	------	------	66.9	73.4	73.5	66.8	64.0	59.7	51.5	------
1931													
Soil, 4-inch depth	50.6	56.3	67.0	72.3	73.6	75.0	89.6	86.0	78.0	69.3	54.1	47.3	68.2
Soil, 8-inch depth	47.5	52.9	61.8	67.4	68.8	70.9	85.0	82.5	75.8	67.9	52.8	44.5	64.8
Soil, 12-inch depth	46.9	54.0	57.4	63.4	68.6	72.3	83.8	83.1	77.8	68.9	54.6	44.7	64.6
Basement	57.9	59.5	61.7	64.2	66.8	68.9	79.4	78.2	74.2	70.2	63.4	59.1	67.0
Air	53.8	56.2	61.8	63.7	67.2	70.0	77.5	74.3	68.0	62.6	53.1	48.6	63.1
1932													
Soil, 4-inch depth	46.0	50.9	66.9	71.7	71.7	77.2	80.5	78.7	75.9	66.9	62.7	49.1	66.5
Soil, 8-inch depth	43.3	49.8	65.1	71.4	71.2	77.0	80.5	78.3	74.7	66.6	61.5	47.7	65.6
Soil, 12-inch depth	45.6	56.0	65.3	71.2	71.0	77.3	80.9	78.8	75.4	67.2	63.5	53.2	67.1
Basement	58.8	62.3	67.0	67.5	69.1	70.9	73.5	74.4	72.8	69.7	68.0	60.5	67.9
Air	47.6	52.3	58.4	59.9	62.3	68.8	72.9	73.0	66.3	62.2	60.7	48.4	61.1
1933													
Soil, 4-inch depth	48.0	55.4	65.2	65.6	68.9	75.9	81.2	80.9	72.4	69.9	61.7	53.0	66.5
Soil, 8-inch depth	45.8	54.8	64.6	65.8	68.3	74.7	80.2	80.5	71.9	68.9	61.5	53.8	65.9
Soil, 12-inch depth	50.4	54.7	63.6	65.3	68.1	74.2	79.2	79.9	72.7	71.4	63.0	54.5	66.4
Basement	58.7	60.1	63.7	65.2	65.8	70.0	73.5	74.7	70.5	72.7	68.1	63.6	67.2
Air	47.2	50.0	54.6	56.2	58.2	64.1	69.6	69.4	61.9	63.6	58.9	52.2	58.8
1934													
Soil, 4-inch depth	53.4	57.0	63.8	69.5	76.0	71.8	78.2	79.1	75.9	68.2	60.8	55.9	67.5
Soil, 8-inch depth	53.7	56.8	63.3	68.7	75.2	71.6	77.7	81.2	78.5	70.8	62.9	57.1	68.1
Soil, 12-inch depth	53.8	56.9	63.1	68.2	75.4	71.8	77.8	80.2	77.7	70.1	62.1	57.3	67.9
Basement	62.9	65.2	69.6	70.2	72.7	70.9	76.3	76.3	75.0	71.1	66.4	62.5	69.9
Air	53.1	53.1	62.6	62.8	66.9	64.7	72.4	69.9	69.3	62.3	56.4	53.8	62.3

[1] Instrument 3½ feet from soil surface in standard Weather Bureau shelter.

As shown by the annual means, the soil temperatures at the different depths did not fluctuate widely in the successive years. At the 4-inch depth the lowest annual mean recorded was 66.5° F. in 1932 and 1933, and the highest was 68.2° in 1931. Temperatures at the 8-inch depth were also consistent in the different years, ranging from a mean of 64.8° in 1931 to 68.1° in 1934. Temperatures at the 12-inch depth ranged from 64.6° in 1931 to 67.9° in 1934. Maximum monthly soil temperatures at all depths except the 8- and 12-inch depths in 1933 were recorded in July of 1931, 1932, and 1933 and in August of 1934. The lowest temperatures usually occurred in January. An average of the soil temperatures at all depths showed that 1934 was considerably warmer and 1931 cooler than the other years.

Except for 1934, there was only a slight variation in the mean annual basement temperatures. The lowest was 67° F. in 1931 and the highest 69.9° in 1934. Temperatures in the basement were generally lower in January, and the highest were recorded in July and August. During the 4 years there were only slight differences between the mean

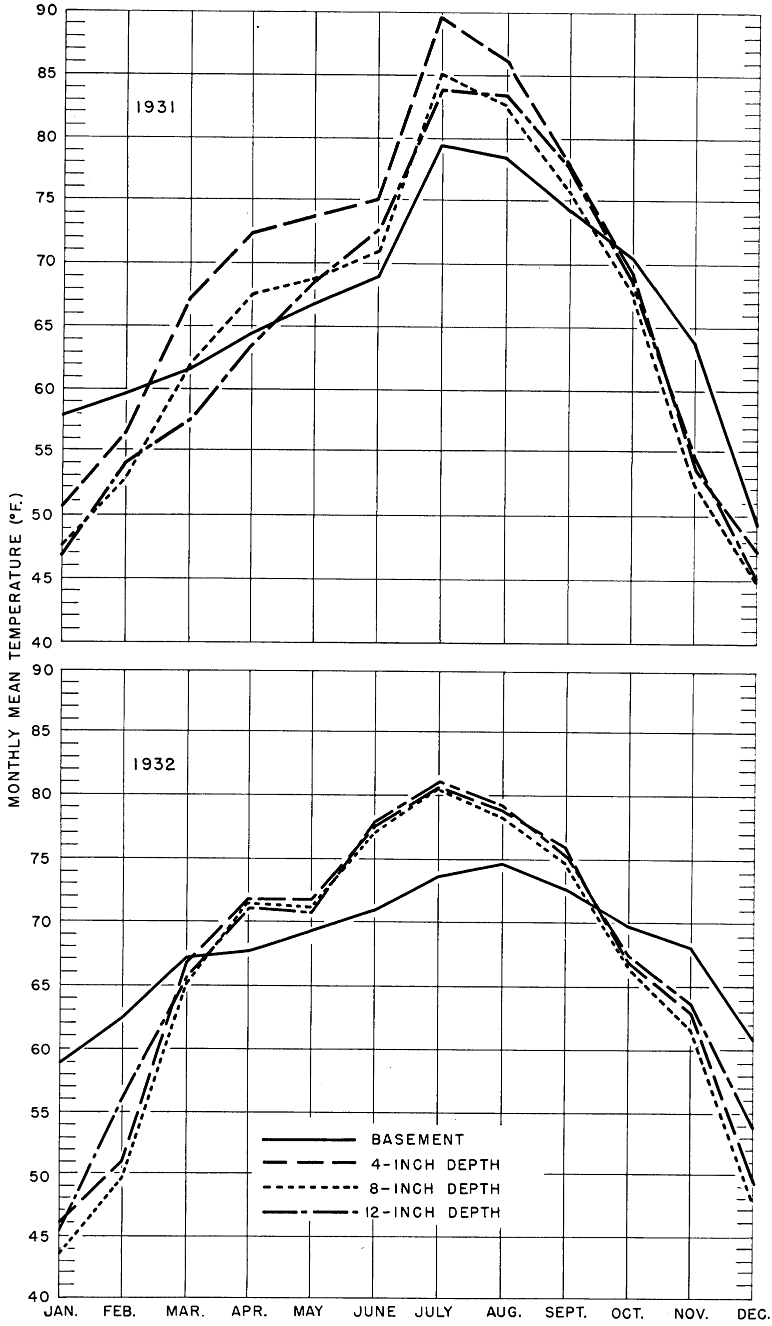

FIGURE 13.—Monthly mean temperatures in the basement where life-history studies on the sugar-beet wireworm were carried on, in comparison with the soil temperatures at the depths of 4, 8, and 12 inches in tile-cage plots. Alhambra, Calif., 1931–34.

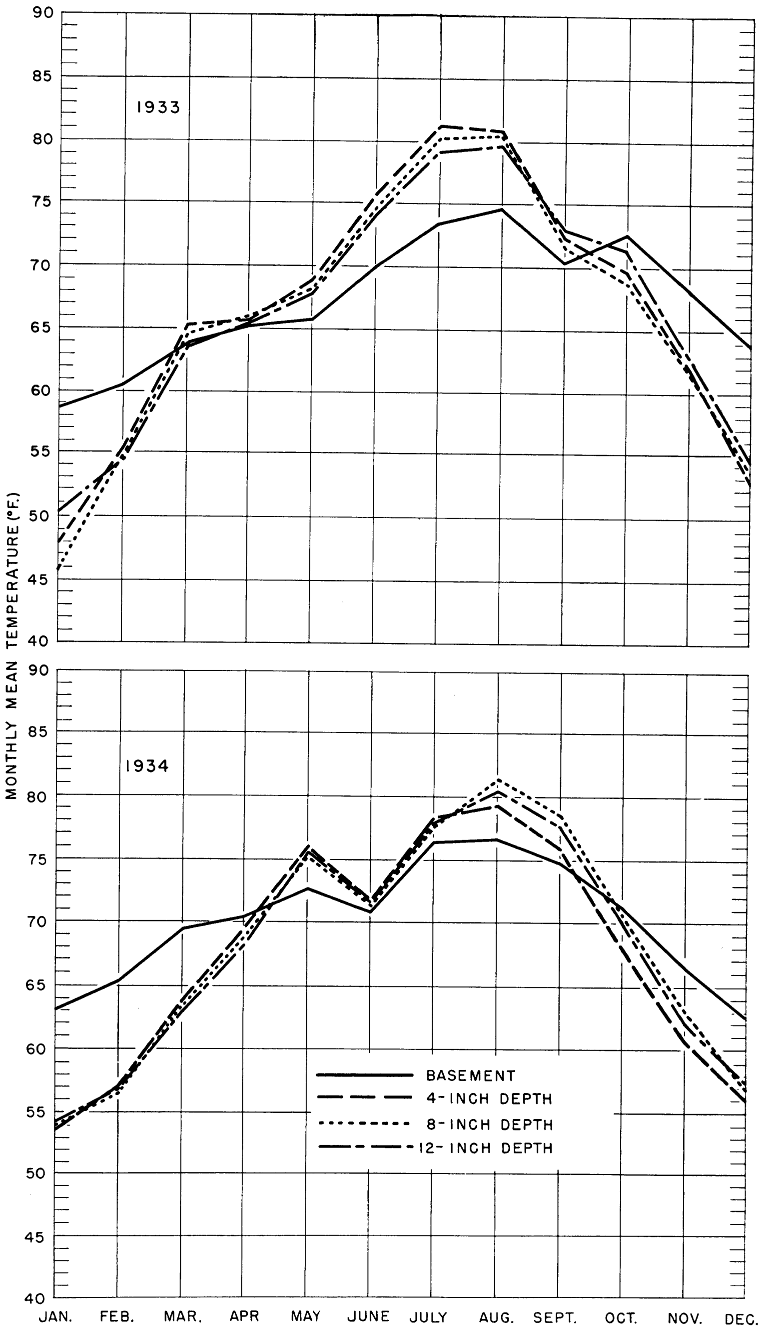

FIGURE 13—Continued

temperatures of the basement and the mean soil temperatures outdoors at the 4-, 8-, and 12-inch depths.

Air temperatures were the highest in 1931, averaging 63.0° F. for the year, and the lowest annual minimum was 58.8° in 1933.

As this investigation dealt primarily with the sugar-beet wireworm in the irrigated sections, the data on precipitation have not been considered.

THE EGG

DEPTH IN SOIL AND PLACES CHOSEN FOR OVIPOSITION

During the spring of 1932 studies were conducted to ascertain the depth at which eggs are deposited in moist and dry soils. Series A consisted of four glass tubes, each 1½ by 7 inches in length, which were packed firmly to within 1 inch of the top with soil sifted through a 60-mesh screen and containing 14 percent of moisture by weight. In series B, 3 inches of soil with 14 percent of moisture was packed in the bottom of the tubes, on top of which was put 2½ inches of soil containing 5 percent of moisture. A fertile female was then placed in the top of each tube, and vials were securely stoppered and placed in a constant-temperature cabinet at 70° F. After 3 weeks the tubes were marked outside in ½-inch divisions, and each half inch of soil was removed and washed through a sieve and the eggs carefully counted.

The results, as illustrated in figure 14, show that in the tubes with moist soil nearly 50 percent of the eggs were deposited in the first inch, whereas in the drier soil no eggs were recovered at this depth. During the examination of these tubes it was noted that the soil with the 5-percent water between the 2- and 2½-inch depths had absorbed a small quantity of moisture from the damper soil. Undoubtedly this explains the presence of a few eggs above the 2½-inch level. As most of the eggs were deposited below the 2½-inch depth, it appears that females, when compelled to do so, will burrow to a depth of 4 inches or lower to oviposit, in order to provide the eggs with an optimum of moisture during their incubation period. No observations were made on the depths of eggs deposited in the field.

The presence or absence of vegetation does not appear to be a factor in the selection of sites by ovipositing females, as the majority of lima bean fields that are heavily infested are continuously under clean cultivation and void of vegetation during the oviposition period. Firmly packed, heavy soils appear to offer no resistance, as these crack readily after rains to a depth of several inches. These cracks or crevices are not only utilized as places for oviposition but offer protection to the females during high temperatures and strong winds. As shown in the experiment, the drier soil containing 5 percent of moisture was readily penetrated by the females for a depth of 2 or more inches so that they might oviposit in the moist soil underneath. There is little likelihood, however, that oviposition would be hindered by a low moisture content, as during the period of female activity the surface soil in most of the bean and sugar-beet fields is kept moist, either by rains or by irrigation.

The oviposition studies in the laboratory and observations in the field indicate that loose soils ranging in moisture content from 10 to 18 percent are preferred by the adults as places for egg deposition.

INCUBATION PERIOD

Incubation records were obtained from eggs which had been deposited in salve tins two-thirds full of fine soil containing approximately 12 percent of moisture.

The eggs were sifted from this soil on alternate days and the date of deposition of that group of eggs marked as of the day preceding.

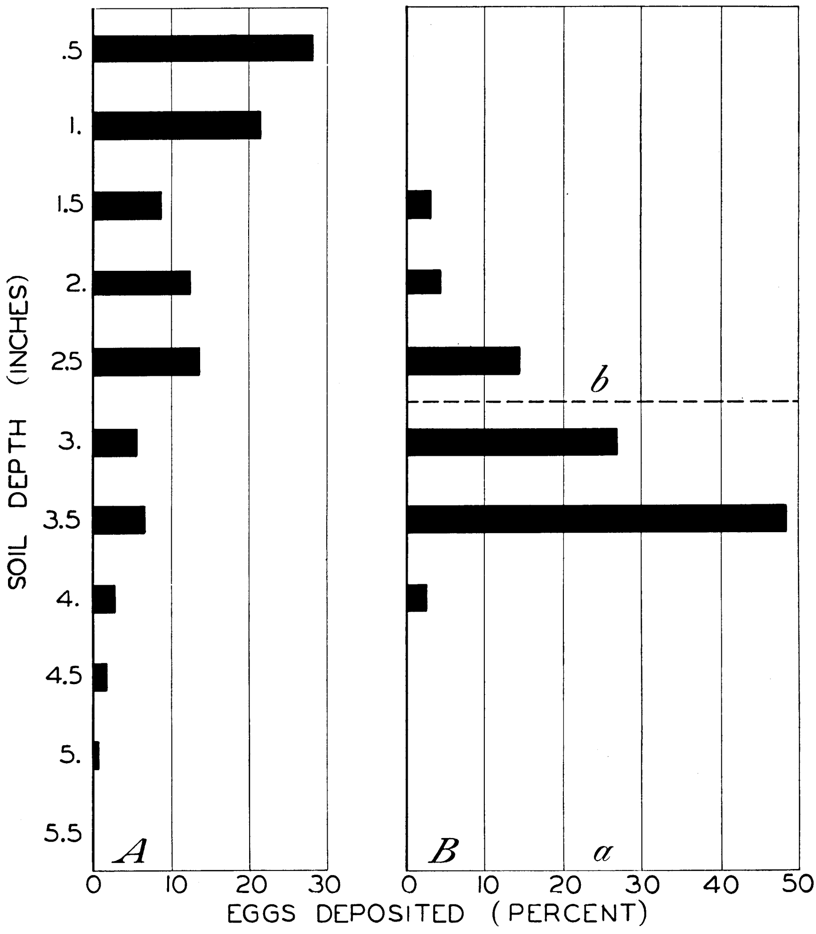

FIGURE 14.—Depths at which eggs were deposited in the soil by adults of the sugar-beet wireworm, Alhambra, Calif.: *A*, Soil containing uniformly 14 percent of moisture; *B*, soil with 14 percent of moisture at the bottom (*a*) and 5 percent at the top (*b*).

As time for hatching approached, and thereafter until hatching had ceased, the eggs were washed from the soil each day.

Records on the duration of the incubation periods for 968 eggs laid during the period February 20 to May 6, 1931, which hatched over a period of 63 days from March 30 to May 31, inclusive, showed clearly the variation in the incubation period and its relation to temperature.

For instance, an average of 37 days was recorded for the eggs laid in February under a mean of 61.5° F., and when temperatures in March increased to 64° the period was shortened to 30.4 days. Temperatures during April and May were still higher. As a result, the average length of the period was further decreased to 27.4 and 24.4 days, respectively. The seasonal extremes of incubation were from 23 days in May to 46 in February. Temperatures during the 4-month period averaged 63.9°, and the incubation period averaged 32.6 days.

In 1932 hatching began on March 22 and continued for 79 days until June 8, the records being based on 2,356 eggs deposited between February 24 and May 10. Because of the slight monthly variation in temperature during the incubation period, little difference was recorded in the average length of the period in the different months. The minimum of 26 days occurred in February and the maximum of 34 days in February and March. The average for all eggs was 29.3 days.

The incubation records for 1933 showed that in this year eggs were laid between February 28 and May 9 and hatched over a period of 65 days between April 5 and June 8. The monthly weighted mean ranged from 36.6 days for eggs laid in February, when basement temperatures averaged 64.1° F. to 29.0 days for eggs laid in May when the temperature increased slightly to 66.1°. Average temperatures for March and April differed only 0.5°. As a result there was less than 1 day's difference in the average length of the incubation period during these 2 months. Individual records for the season showed that the egg period ranged from 27 days in May and June to 41 in February to April, the average being 33.7 days.

A summary of the incubation records for the 7,692 eggs under observation during the seasons of 1931, 1932, and 1933 is presented in table 2, and graphically in figure 15. The greatest range in the length of the average incubation period occurred in 1931, from 37 days for eggs deposited in February to 24.4 days for eggs laid in May. Basement temperatures during the 1932 season were abnormally high and shortened the period to an average of 29.3 days. The averages 32.6 and 33.7, obtained in 1931 and 1933, respectively, may be considered fairly representative for the duration of the incubation period in the basement from year to year.

TABLE 2.—*Summary of laboratory incubation records of eggs of Limonius californicus for 1931–33, Alhambra, Calif.*

Month eggs were laid	Incubation period, 1931				Incubation period, 1932				Incubation period, 1933				1931–33
	Records	Range	Weighted mean	Average mean temperature	Records	Range	Weighted mean	Average mean temperature	Records	Range	Weighted mean	Average mean temperature	Weighted mean
	No.	*Days*	*Days*	°*F.*	*No.*	*Days*	*Days*	°*F.*	*No.*	*Days*	*Days*	°*F.*	*Days*
February	532	31–46	37.0	61.5	188	26–34	28.4	66.9	65	36–41	36.6	64.1	35.1
March	43	30–31	30.4	64.0	1,696	27–34	29.2	67.7	2,898	31–40	33.9	64.6	32.2
April	331	26–32	27.4	65.8	415	28–30	28.9	67.8	1,374	28–37	33.3	65.1	30.7
May	62	23–27	24.4	66.9	57	29–29	29.0	69.3	31	27–30	29.0	66.1	27.2
Total or average	968	23–46	32.6	63.9	2,356	26–34	29.3	67.7	4,368	27–41	33.7	65.0	32.2

It will be seen that in general the incubation period is longest for the eggs laid in February but gradually shortens as the temperature rises through March, April, and May.

INCUBATION IN SUNNY AND SHADED LOCALITIES

Most of the fields in infested localities are under clean cultivation during the period of beetle activity, and the topsoil is usually low in moisture to a depth of several inches. Under these conditions adults oviposit below the dry layer in the moist soil (fig. 14). To compare the lengths of the incubation period of eggs deposited in soils exposed to the sun and those in soils in the shade with the records obtained for eggs kept in the basement, salve cans containing newly deposited eggs were placed at a depth of 2 inches in ground exposed to the sun and in ground constantly shaded, and covered with a layer of dry soil. Re-

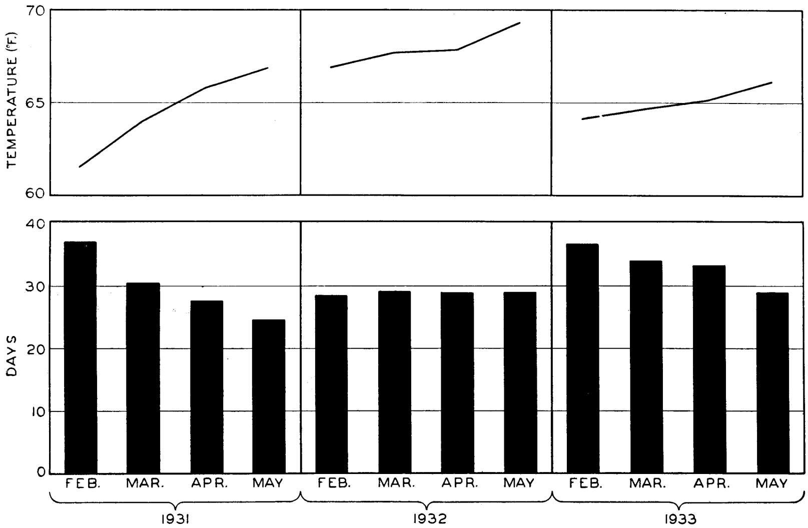

FIGURE 15.—Length of the incubation period of eggs of *Limonius californicus* in salve cans compared with the mean basement temperature at the Alhambra, Calif., laboratory, 1931–33.

cording thermometers were installed to measure the soil temperature 2 inches below the surface in the different localities.

At this time of the year there was but a slight difference in the average temperature 2 inches deep in a soil exposed to the sun and the temperature in the basement. Soil temperatures during the incubation period of eggs deposited on February 28 averaged 67.6° F., or 0.6° higher, and for eggs deposited March 11, 71.5°, or 3.8° higher, than those recorded in the basement for February 25 [7] and March 11. The duration of the egg stage for the earlier-deposited eggs averaged 29.9 days, and for the later-deposited eggs 26.2 days, as compared with averages of 29.5 and 29.1 days, respectively, in the basement.

Temperatures at the 2-inch depth in the shade were low (62.4°) and as a result the incubation period was prolonged to as much as 50 days.

[7] As only 2 eggs were deposited on February 28, in the basement, the records for the 108 eggs deposited on February 25 were used.

The Larva

DEVELOPMENTAL PERIOD

Because knowledge of adult behavior and of the necessary rearing technique or equipment was lacking, the rearing studies begun in 1929 were not so complete as could be desired. Fertile females collected in the field were placed in moist, fine-mesh soil in 1-ounce salve cans and confined in the laboratory basement (fig. 16), where they were allowed to oviposit unmolested. After several weeks had elapsed, the soil in the salve cans was removed daily and examined under a binocular microscope for newly hatched larvae. When these were found, they were transferred individually to other salve cans containing fine-mesh soil and 3 or 4 kernels of wheat. Later, as the larvae increased in

Figure 16.—Basement room in the Alhambra, Calif., laboratory where sugar-beet wireworms were reared in salve cans.

size, they were fed 8 to 10 kernels of wheat monthly, depending on the season.

A total of 45 larvae that hatched late in the season (May 27 to June 12) were used in the rearing studies begun in 1929. The duration of the developmental periods is summarized in the first 3 lines of table 3. Seven larvae died leaving only 38 to show completed records. Five of the deaths occurred in the second year.

The first pupation occurred August 21, 1930. During August and September, 22 individuals completed development after an average larval period of 464.9 days. Fourteen of the remainder pupated between August 26 and October 6 in 1931, and 2 in August 1932, after average larval periods of 830.8 and 1,167.5 days, respectively.

The larvae used in the rearing studies of 1930 were obtained by the same procedure as used in 1929. A total of 368 larvae were under observation at the beginning of the study, but 63 died, 41 in the second

year. The eggs hatched late in the season, between May 8 and 22, and the larvae were fed 10 kernels of wheat monthly throughout the year. A summary of the data pertaining to these rearings also appears in table 3.

TABLE 3.—*Duration of the developmental periods of the sugar-beet wireworm in the laboratory, Alhambra, Calif., 1929–31*

Year eggs hatched	Life cycle	Individuals	Average egg period	Average larval period [1]	Average prepupal period	Average pupal period	Average larval and pupal periods [2]
	Years	*Number*	*Days*	*Days*	*Days*	*Days*	*Days*
1929	2	22		464.9±1.6	11.7±0.8	27.7±1.3	492.6±2.1
	3	14		830.8±2.4	7.6±0.5	19.4±0.4	850.2±2.7
	4	2		1,167.5±5.0	5.0	20.5±0.3	1,188.0±5.3
1930	2	201		487.2±0.5	6.6±0.2	19.5±0.1	506.8±0.6
	3	94		843.8±1.0	10.6±0.3	23.6±0.2	867.5±1.1
	4	7		1,218.0±1.8	14.1±1.0	22.0±0.2	1,240.0±1.7
	5	3		1,589.6±1.1	3.0±1.1	22.7±1.2	1,612.3±1.0
1931	1	3	37.3±1.7	159.7±10.8	3.7±0.2	16.7±0.5	213.6±7.6
	2	79	36.8±0.2	527.4±1.0	8.2±0.3	22.8±0.1	587.0±1.0
	3	2	35.5±1.0	911.0±2.0	12.5±1.7	21.0±0.7	967.5±3.7
	4	2	39.0±2.0	1,234.5±2.4	9.5±0.3	18.5±0.3	1,292.0±0.7
	1	47	36.8±0.2	171.3±0.7	4.7±0.3	17.8±0.2	225.9±0.8
	2	163	34.2±0.2	520.5±0.9	7.5±0.2	22.7±0.2	577.4±0.4
	3	8	30.6±1.7	882.2±9.2	8.7±0.7	22.7±0.3	935.5±7.3
	4	3	36.0±1.7	1,273.3±7.2	7.0±2.0	23.0±0.4	1,332.3±8.9

[1] Includes the prepupal period.
[2] The figures for the records for 1931 include the average egg period.

The first pupation in this group occurred in the second year on August 20, 1931, and the last in that year was on October 27. The first and last adults in 1931 appeared on September 5 and November 30, respectively. Of the 54.6 percent of total larvae that matured for a 2-year cycle,[8] over 53 percent were males. Pupations in 1932, which totaled 25.5 percent of the original larvae, began on August 7 and continued until October 7. The first adult was observed on August 31 and the last on November 7. Males again predominated.

In the period September 12 to October 1, 1933, seven individuals completed development for a 4-year cycle, and between September 26 and October 1 in 1934 the three remaining larvae matured, completing a 5-year cycle. The larval period of 1,593 days undergone by one of the latter was the longest recorded during these studies. Among the 4-year larvae the majority were females, while all the 5-year larvae were females. Although the specimens that matured in 1933 and 1934 were exceedingly large larvae, they delayed pupation until late in September of each year, after the majority of the smaller and younger larvae in other rearing experiments had already entered the pupal stage. One would expect that these larger or older larvae would pupate earlier in either July or August.

The data for the 1931 group differ from those for the groups of 1929 and 1930 not only in including the egg stage, but also in that larvae which had hatched about a month earlier than was the case in the two previous years were included. Probably the most surprising discovery was the fact that a few of these earlier-hatched larvae pupated the same year, for a 1-year life cycle.

The studies of growth were made on 100 individuals that hatched during the period March 30 to April 5, inclusive, 1931, from eggs

[8] The elapsed time from the egg to the appearance of the adult in the spring of the second year would be approximately 2 years.

deposited from February 20 to 28, inclusive. Each larva was fed 10 kernels of wheat monthly during the year. One of the 3 individuals that matured in 1931 hatched on April 2 and pupated on August 21, after an elapsed period of 141 days in the larval stage. This was the shortest larval period recorded during these studies. All 3 specimens that matured in this year were males. Pupations in 1932 began on August 11 and terminated October 9. The adults, males of which were slightly in excess, were obtained throughout the period August 31 to November 8.

The 2 specimens that matured in 1933 for a 3-year cycle pupated on September 26 and October 2 and transformed to male adults on October 16 and 24, respectively. Pupations in 1934 occurred on August 20 and 21, and the 2 females emerged for a 4-year cycle on September 7 and 9, respectively. Fourteen of the 100 larvae died without pupating, 7 in the first year and 6 in the second.

Another rearing series begun in 1931 consisted of 250 sugar-beet wireworms that hatched between March 27 and May 26, from eggs deposited in the period February 20 to April 27. The individuals in this group were also fed 10 kernels of wheat monthly. Twenty-nine of them failed to reach maturity, 13 and 14 dying in the first and second years, respectively.

The outstanding fact in this experiment, the data for which are shown in the last 4 lines of table 3, was the large increase of individuals completing development in the first year. In the group of 100 just discussed only 3 percent matured in the first year, whereas in this experiment, in which larvae of approximately the same age were used, 18.8 percent completed development in a 1-year cycle. No sex determinations were made on the latter, but owing to their small size it is believed that the majority were males. The first pupation occurred on August 28, or after an approximate period of 5 months from the time of hatching. Pupation continued in 1931 throughout September and terminated October 10.

Of the 163 larvae that matured in 1932 for a 2-year cycle, the first pupated on August 22 and the last on October 24. The former transformed to an adult on September 12 and the latter on November 21. In this group males were slightly in excess.

Pupations in 1933 of the eight individuals completing development for a 3-year cycle began later than usual, on September 12, and ended October 18. First and last beetles were taken on October 5 and November 13. Females outnumbered the males 7 to 1 in this case. The remaining three larvae that matured for a 4-year cycle in 1934 pupated between September 23 and October 14 and these emerged as two females and a male between October 16 and November 7, inclusive. In this as well as in other experiments although all the individuals that matured in 1 year were from early-laid eggs, individuals also were found in the 2-, 3-, and 4-year cycles from the early as well as the later-produced eggs. It is apparent that under favorable conditions, especially of temperature, growth is accelerated, but it is also apparent that within any group under similar conditions there is considerable individual variation in rate of growth and size.

The proportions maturing after life cycles of 1, 2, 3, 4, and 5 years are shown graphically in figure 17.

The duration of the larval period in the foregoing salve-can rearings averaged 170.6, 504.6, 846.2, 1,225.0, and 1,589.6 days for those maturing in 1, 2, 3, 4, and 5 years, respectively.

Basement temperatures during the larval period were in general the same each year, averaging 67° or 69° F. throughout the entire year, but they naturally averaged higher (71.8°) for the records of those larvae that completed development in 1 year and did not pass through a winter.

The beginning of an attempt to record the different molts and the amount of wheat eaten by larvae in completing development was made in 1931. Owing to the difficulty in ascertaining whether the kernels had been eaten or destroyed by fungus, this latter phase was discontinued until time permitted weekly instead of monthly examinations. Owing to the minute size of the earlier exuvia and the difficulty in locating these, the keeping of molt records was not begun until July 1, after which both larvae and molted skins were of such size as to be readily perceptible in the soil.

For larvae completing development in the second year, the number of molts recorded from July 1 averaged 6, for the third-year individuals the average was 7 molts, and for those maturing in 4 years the average was 12 molts. An examination of the data in table 11 for larvae that matured in 2 years shows that possibly 4 molts were missed. The average number would then be approximately 10, 11, and 16 molts for larvae completing development in the second, third, and fourth years, respectively. More accurate records were obtained by a different method and these are given later under appropriate headings.

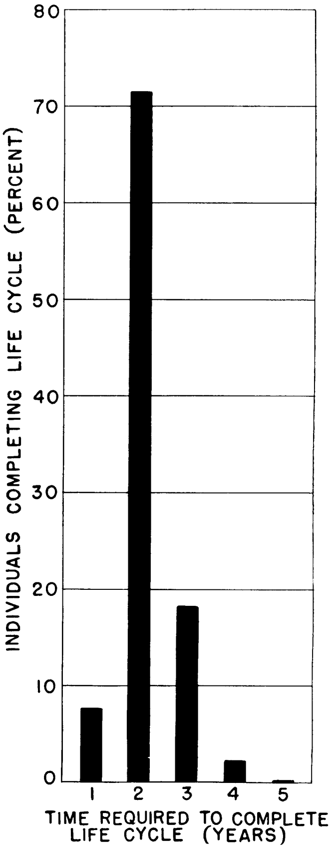

FIGURE 17.—Proportions of sugar-beet wireworms of the broods beginning development in 1929, 1930, and 1931, completing the life cycle in the indicated numbers of years.

Since the previous rearing studies indicated that when the larvae hatched early in the season a greater number of them would pupate the first year, owing to the extended period of feeding, it was desired to obtain additional data as to the effect of time of hatching on the rate of pupation in the first and in later years. With this in view a number of larvae of the brood of 1932 were segregated into 3 well separated groups according to their date of hatching. Group 1 consisted of 40 larvae that hatched between March 23 and 30, from eggs deposited in the period February 24 to 28. The 40 larvae in group 2 hatched between April 15 and May 26, from eggs deposited between

March 17 and April 28. Group 3 consisted of 39 larvae hatched on June 8 from eggs deposited on May 10. Each larva in the different groups was fed 10 kernels of wheat monthly. A summary of the results appears in tables 4 and 5.

TABLE 4.—*Duration of the developmental periods of 3 groups of sugar-beet wireworms hatched at different times in 1932, reared in salve cans, and fed 10 kernels of wheat monthly, Alhambra, Calif.*

EARLY-HATCHED GROUP (MARCH 23-30)

Life cycle (years)	Individuals	Item	Duration of period: Egg	Larval [1]	Prepupal	Pupal	Egg, larval, and pupal	Temperature [2]
	Number		*Days*	*Days*	*Days*	*Days*	*Days*	*° F.*
1	3	Maximum	29	173	36	23	221	
		Minimum	26	155	13	22	207	
		Average	28.0±0.7	162.3± 3.6	28.0±5.0	22.3±0.2	212.6± 2.8	71.1
2	20	Maximum	33	544	13	24	597	
		Minimum	26	514	5	21	566	
		Average	29.3±0.2	537.6± 1.0	9.5±0.4	22.3±0.1	589.2± 0.9	68.2
3	8	Maximum	30	919	11	23	967	
		Minimum	26	892	3	21	941	
		Average	28.2±0.2	910.6± 1.9	6.7±0.6	22.0±0.4	960.8± 2.4	69.1
4	1		30.0	1,293.0	11.0	27.0	1,350.0	68.7

INTERMEDIATE-HATCHED GROUP (APRIL 15 TO MAY 26)

Life cycle (years)	Individuals	Item	Egg	Larval [1]	Prepupal	Pupal	Egg, larval, and pupal	Temperature [2]
2	25	Maximum	31	533	15	25	583	
		Minimum	28	475	5	21	526	
		Average	29.0±0.1	507.9± 2.0	9.7±3.2	22.5±0.1	559.4± 2.4	68.2
3	6	Maximum	31	907	25	23	958	
		Minimum	27	816	6	19	907	
		Average	28.7±0.4	871.7± 8.6	10.5±2.0	21.5±0.6	936.0± 7.6	69.0
4	3	Maximum	29	1,256	6	25	1,310	
		Minimum	29	1,251	1	24	1,304	
		Average	29.0±0.0	1,253.7± 1.0	3.7±0.9	24.3±0.2	1,307.0± 1.1	68.7

LATE-HATCHED GROUP (JUNE 8)

Life cycle (years)	Individuals	Item	Egg	Larval [1]	Prepupal	Pupal	Egg, larval, and pupal	Temperature [2]
2	23	Maximum	29	476	13	25	528	
		Minimum	29	438	5	21	490	
		Average	29.0±0.0	459.5± 1.0	9.1±0.3	23.5±0.8	512.0± 0.9	68.2
3	6	Maximum	29	836	15	23	888	
		Minimum	29	735	2	18	783	
		Average	29.0±0.0	807.0±10.0	8.3±1.9	20.2±0.5	856.2±10.6	68.9

[1] Prepupal period included in larval period.
[2] Average of daily mean temperatures during larval period.

In the early-hatched group three larvae matured as males in 1932 in a 1-year cycle, whereas in the two later-hatched groups none completed development the first year, apparently owing to the shortened feeding period. Pupations in this group in 1932 began August 30 and terminated September 13.

TABLE 5.—*Summary of pupations, mortality, and sex ratios of the 1932 brood of the sugar-beet wireworm, Alhambra, Calif., 1932–35*

Item	Pupation and mortality data								Sex ratio [1]	
	Group 1, early hatch		Group 2, intermediate		Group 3, late hatch		Total, all groups		Males	Females
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
Pupations:										
1932, 1-year cycle	3	7.5	0	0.0	0	0.0	3	2.5	100.0	0.0
1933, 2-year cycle	20	50.0	25	62.5	23	59.0	68	57.1	51.4	48.6
1934, 3-year cycle	8	20.0	6	15.0	6	15.4	20	16.8	30.0	70.0
1935, 4-year cycle	1	2.5	3	7.5	0	0	4	3.4	0	100.0
Mortality	8	20.0	6	15.0	10	25.6	24	20.2		
Total	40	100.0	40	100.0	39	100.0	119	100.0	46.6	53.4
Larval mortality:										
1932	6	15.0	4	10.0	6	15.4	16	13.4		
1933	2	5.0	2	5.0	3	7.7	7	5.9		
1934	0	0	0	0	1	2.6	1	0.8		
1935	0	0	0	0	0	0	0	0		

[1] The sex determinations were not made until after some of the adults had been lost or destroyed by fungus. Consequently the sex ratio was based on the individuals whose sex could be established at the time of examination, and does not in all instances represent the total number of adults that emerged.

Early hatching of larvae appeared not to accelerate the rate of pupation in the second year, as the pupation percentage in 1933 was even lower for the early group than that recorded in the two later-hatched groups. In this year the earliest pupations occurred on August 20 in the intermediate- and late-hatched groups, and the last pupation was on October 2. The adults, almost evenly divided between the sexes, emerged in the period September 12 to October 24.

In 1934 the percentage of pupating individuals was slightly greater in the early-hatched group than in the others. The earliest observed pupation recorded during these studies occurred on June 13 in the late-hatched group. This specimen transformed to adult on July 2. The last pupation was from the intermediate-hatched larvae, on October 9, and the last adult emerged on October 31. In this year females predominated over the males in all groups.

In 1935 pupations of the remaining larvae, which belonged to the early- and intermediate-hatched groups, began later than usual, on September 18, and terminated October 9. All four specimens, which emerged between October 12 and November 5, were females.

A summary of the pupations in all groups shows that of the 119 larvae at the start of the experiment the majority, or 57.1 percent, matured in the second, and 16.8 percent in the third year. Group totals showed that 80 percent of the early-, 85-percent of the intermediate-, and 74.4 percent of the late-hatched groups completed development. The sex ratio for the entire brood was 46.6 percent males and 53.4 percent females.

Apparently pupation of sugar-beet wireworms takes place during the usual period regardless of the time of hatching. This is verified by the fact that not only the average but the maximum and minimum durations of the larval period in the different years were less for the second and succeeding years in the late-hatched groups than among the early-hatched larvae.

EFFECT OF QUANTITY OF FOOD ON RATE OF LARVAL DEVELOPMENT

In previous wireworm-rearing experiments 10 kernels of wheat were given the individual larvae at each monthly examination. Later feeding studies showed this quantity to be adequate. During the first year of larval life, in July, August, and September, the number of kernels eaten monthly in several instances reached a maximum of 17, the monthly average ranging from 12.1 kernels in July to 15.4 in September. Averages slightly in excess of 10 kernels were also recorded for October of the second year and for May of the third year of larval life.

An experiment was started in March 1930 to determine the effects of small as compared with large quantities of food on the rate of pupation. The results are summarized in table 6. Groups 1 and 2 consisting of 10 and 15 larvae, respectively, were fed individually 1 kernel of wheat monthly, and the 25 larvae in group 3 were fed 8 kernels of wheat monthly. The results of this experiment show that the rate of pupation is lessened when only small quantities of food are available and that the larvae are capable of existing under such adverse conditions for 5 or more years; also, that they pupate readily when their food supply is increased.

TABLE 6.—*Effect of various quantities of food on the rate of larval development of the sugar-beet wireworm, Alhambra, Calif., 1930–34*

Item	Larval development and mortality data for—					
	Group 1 [1]		Group 2 [2]		Group 3 [3]	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Pupations:						
1931, 2-year cycle	0	0	1	6.67	14	56.0
1932, 3-year cycle	0	0	2	13.33	2	8.0
1933, 4-year cycle	0	0	0	0	1	4.0
1934, 5-year cycle	3	30.0	8	53.33	1	4.0
Mortality	2	20.0	4	26.67	7	28.0
Continued to 1935 or later	5	50.0	0	0	0	0
Total	10	100.0	15	100.0	25	100.0

[1] Fed 1 kernel of wheat each per month from date of hatching.
[2] Fed as group 1 until March 1934, after which fed 8 kernels each per month.
[3] Fed 8 kernels of wheat each per month from date of hatching.

To determine further the effects of various quantities of food on the rate of development of the sugar-beet wireworm, a series of 138 larvae that had hatched between March 23 and May 4 from eggs deposited between February 24 and April 3, 1932, was divided into 3 groups and fed individually each month as follows: The 30 larvae in group 1 were fed 10 kernels of wheat monthly except during the period between October 1 and March 1, when the soil was changed monthly but they were given no food. This period of starvation of the larvae in salve cans was intended to resemble a similar condition in an infested field void of crops during the winter. The 30 larvae in group 2 were supplied with an abundance of food, 20 kernels each month; while those in group 3, totaling 78 larvae, were fed the usual 10 kernels of wheat monthly.

The results showed that the majority of pupations in all groups occurred in the second year and that the pupation percentage in group 1, although fed 10 kernels monthly and starved during the winter period, was identical to the percentage obtained in group 2,

fed 20 kernels monthly. The pupation percentages in the third year were very similar in the 2 groups. Group 3, fed 10 kernels monthly, had a lower percentage of second-year pupations but an increase in the third year. When the percentages of pupations for both years in all groups were combined it was observed that the percentage in group 1 was slightly higher, totaling 90, as compared with percentages of 86.7 and 82.1 in groups 2 and 3, respectively. Although deprived of food for a period of 5 months, the mortality of larvae in group 1 was 10 percent as compared with 17.9 percent in group 3 which were fed 10 kernels continuously. The evidence presented, though meager, indicated that a monthly diet of 10 kernels during the period when larvae are most active is as advantageous to larval development, or more so, as a diet of 10 to 20 kernels of wheat fed monthly throughout the year. In other words, there would be no retardation in the development of larvae inhabiting fields not cropped during the winter months if sufficient food were available during the spring and summer.

Of the 138 larvae used in these studies, 78, or 56.5 percent, matured the second year and 39, or 28.3 percent, the third year. A total of 21 larvae, or 15.2 percent, succumbed. Sexes were equal the second year, but more females than males matured the third year. There was less than a day's difference in the average length of the larval period for the 2-year-cycle individuals in all groups. The average larval period for the 3-year-cycle specimens ranged from 884.6 days in group 3 to 901.5 days in group 1.

To substantiate the studies begun in 1932 on the effects of various quantities of wheat on the rate of pupation and the duration of the larval period, a similar experiment was begun in 1933 on a much larger scale. In this experiment 450 larvae that had hatched early, at an intermediate time, and late in the season were segregated into 3 groups of 150 each and fed individually each month as follows: The larvae in group 1 were fed 10 kernels of wheat, larvae in group 2 were fed 20 kernels, and larvae in group 3 were fed 10 kernels, except for the period between October 1 and March 1, when the only treatment was a change of soil each month.

Each of these groups was further divided into lots of 50 each according to the dates of hatching. One lot in each group hatched between April 5 and 10, from eggs laid between February 28 and March 5; an intermediate lot hatched between April 23 and 28, from eggs laid between March 21 and 28; and the third hatched between May 20 and June 8, from eggs deposited between April 16 and May 9.

The results, as to the duration of the stages, were similar to those obtained in the studies of 1932, which were on a smaller scale but with the same quantities of food.

There were very slight differences in the number of individuals completing development in the 3 groups fed different quantities of wheat, and larval development was not retarded in the least when food was not provided during the winter months, nor was development accelerated by the continuous feeding of 20 kernels of wheat per month throughout the year. This indicates that the feeding by larvae during the winter period is negligible and consequently their development is not hastened by the presence of food in any year of their life in the period from October through February, inclusive.

Contrary to previous results, the time of hatching of the larvae in these studies appeared to have had no effect on the rate of pupation

in the first year. The 20-kernel group had 4 larvae that matured for a 1-year cycle as contrasted with 2 pupations in each of the other groups. This small number was due possibly to the lower temperature that prevailed in the basement during April and May of 1933, which retarded feeding and, subsequently, the development of the larvae during their first year. Temperatures in the basement during the spring and summer of 1934 were well above normal, resulting in increased food consumption and in a greater percentage of second-year pupations than was recorded in previous studies.

The duration of the larval period for individuals of the 1-, 2-, and 3-year cycles varied in the different groups according to the time of hatching. In the early hatch the average for individuals of the 1-year cycle in group 2 was 205 days, whereas in the intermediate hatch 1 individual in group 1 matured after 190 days and for the 2 specimens in group 3 the average was 154 days. One 1-year larva in group 1 and 1 in group 2 of the later-hatch larvae completed their development in 156 and 150 days, respectively. The duration of the larval period for the 2-year-cycle specimens in group 1, fed 10 kernels continuously, ranged from 515.8 days for the early hatch to 501.8 days and 472.1 days for the larvae hatching at an intermediate time and late in the season. The averages decreased accordingly in the other groups from 519 to 510.7 and 476.7 days in group 2, and from 509.5 to 498.2 and 469.6 days in group 3, for the early-, intermediate-, and late-hatched larvae, respectively. A similar decrease is shown for the individuals completing development in the third year of larval life.

The duration of the larval period in the group starved during the winter averaged slightly less than in the other groups fed 20 and 10 kernels each month. This further corroborates the evidence presented earlier, that winter feeding does not hasten the growth of the larvae or the subsequent rate of pupation in any group.

TABLE 7.—*Summary of pupations, larval mortalities, and sex ratios of the 1933 brood, early-, intermediate-, and late-hatched sugar-beet wireworms; 50 specimens in each of the nine lots; Alhambra, Calif.*

GROUP 1, FED 10 KERNELS OF WHEAT MONTHLY

Item	Pupation and mortality data for individuals—								Sex ratio [1]	
	Hatched Apr. 5–10		Hatched Apr. 23–28		Hatched May 20–June 8		Total		Males	Females
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
Pupations:										
1933, 1-year cycle	0	0	1	2	1	2	2	1.3	50	50
1934, 2-year cycle	43	86	42	84	46	92	131	87.3	48.8	41.2
1935, 3-year cycle	1	2	3	6	1	2	5	3.3	25	75
Total	44	88	46	92	48	96	138	92.0	48.1	51.9
Larval mortality:										
1933	0	0	0	0	0	0	0	0	------	------
1934	5	10	1	2	2	4	8	5.3	------	------
1935	1	2	0	0	0	0	1	.7	------	------
Total	6	12	1	2	2	4	9	6.0	------	------
Continuing as larvae to 1936	0	0	3	6	0	0	3	2.0	------	------

[1] The sex determinations were not made until after some of the adults were lost or destroyed by fungus. Consequently the sex ratio was based on the individuals whose sex could be established at the time of examination, and does not in all instances represent the total number of adults that emerged.

TABLE 7.—*Summary of pupations, larval mortalities, and sex ratios of the 1933 brood, early-, intermediate-, and late-hatched sugar-beet wireworms; 50 specimens in each of the nine lots; Alhambra, Calif.*—Continued

Item	Pupation and mortality data for individuals—								Sex ratio	
	Hatched Apr. 5-10		Hatched Apr. 23-28		Hatched May 20-June 8		Total		Males	Females
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
GROUP 2, FED 20 KERNELS OF WHEAT MONTHLY										
Pupations:										
1933, 1-year cycle	3	6	0	0	1	2	4	2.7	100	0
1934, 2-year cycle	40	80	46	92	43	86	129	86.0	50.0	50
1935, 3-year cycle	0	0	2	4	0	0	2	1.3	50	50
Total	43	86	48	96	44	88	135	90.0	51.5	48.5
Larval mortality:										
1933	3	6	1	2	0	0	4	2.7	-------	-------
1934	2	4	1	2	5	10	8	5.3	-------	-------
1935	1	2	0	0	0	0	1	.7	-------	-------
Total	6	12	2	4	5	10	13	8.7	-------	-------
Continuing as larvae to 1936	1	2	0	0	1	2	2	1.3	-------	-------
GROUP 3, FED 10 KERNELS OF WHEAT MONTHLY [Except period from Oct. 1 to Mar. 1, inclusive][2]										
Pupations:										
1933, 1-year cycle	0	0	2	4	0	0	2	1.3	100	-------
1934, 2-year cycle	44	88	45	90	45	90	134	89.3	47.3	52.7
1935, 3-year cycle	0	0	0	0	1	2	1	.7	0	100
Total	44	88	47	94	46	92	137	91.3	48.5	51.5
Larval mortality:										
1933	0	0	0	0	0	0	0	0	-------	-------
1934	6	12	0	0	3	6	9	6.0	-------	-------
1935	0	0	2	4	1	2	3	2.0	-------	-------
Total	6	12	2	4	4	8	12	8.0	-------	-------
Continuing as larvae to 1936	0	0	1	2	0	0	1	.7	-------	-------
TOTAL—GROUPS 1, 2, AND 3										
Pupations:										
1933, 1-year cycle	3	2.0	3	2.0	2	1.3	8	1.8	87.5	12.5
1934, 2-year cycle	127	84.7	133	88.7	134	89.3	394	87.5	48.7	51.3
1935, 3-year cycle	1	.7	5	3.3	2	1.3	8	1.8	42.8	57.2
Total	131	87.3	141	94.0	138	92.0	410	91.1	49.4	50.6
Larval mortality:										
1933	3	2.0	1	.7	0	0	4	.9	-------	-------
1934	13	8.7	2	1.3	10	6.7	25	5.5	-------	-------
1935	2	1.3	2	1.3	1	.7	5	1.1	-------	-------
Total	18	12.0	5	3.3	11	7.3	34	7.5	-------	-------
Continuing as larvae to 1936	1	.7	4	2.7	1	.7	6	1.3	-------	-------

[2] Soil changed monthly only.

The larval mortality was low, with a range of from 8.7 percent in the 20-kernel group to 6 percent in the 10-kernel group. The greatest mortality was in the early-hatched and the least in the intermediate-hatched group. For all groups, the mortality, resulting either from improper handling or from natural causes, totaled 34, or 7.5 percent.

EFFECT OF CONSTANT TEMPERATURES ON RATE OF DEVELOPMENT

In the studies on the effects of constant temperatures on the larvae of *Limonius californicus* ordinary insulated wooden cabinets were employed. Heat was furnished by incandescent lights under thermostatic control. No attempt was made to control the humidity. The larvae held at 70° F. were fed individually 8 kernels of wheat monthly, and those of the group confined at 80° were fed 10 kernels semimonthly. All stages of the insect in these rearing groups were held at their respective group temperatures. Data pertaining to the rearing of the various stages of *L. californicus* at these temperatures are shown in tables 8 and 9.

TABLE 8.—*Duration of the developmental periods of the 1931 brood of the sugar-beet wireworm, at constant temperatures of 70° and 80° F., Alhambra, Calif.*

Life cycle (years)	Individuals	Item	Duration of period				
			Egg	Larval [1]	Prepupal	Pupal	Egg, larval, and pupal
AT CONSTANT TEMPERATURE OF 70° F.							
	Number		*Days*	*Days*	*Days*	*Days*	*Days*
1	6	Maximum	21	193	8	18	231
		Minimum	18	153	3	16	188
		Average	19.8±0.4	168.8±5.1	5.2±0.5	17.0±0.2	205.7±4.9
2	26	Maximum	29	559	25	26	602
		Minimum	19	336	1	19	385
		Average	21.3±0.4	505.8±7.2	9.3±0.8	21.3±0.3	548.3±7.1
3	2	Maximum	19	927	13	22	967
		Minimum	19	882	4	21	923
		Average	19.0±0.0	904.5±15.1	8.5±3.0	21.5±0.3	945.0±14.8
4	6	Maximum	24	1,285	10	22	1,329
		Minimum	19	1,260	3	20	1,302
		Average	21.0±0.7	1,275.3±2.6	6.3±0.8	20.7±0.2	1,315.0±2.8
AT CONSTANT TEMPERATURE OF 80° F.							
1	20	Maximum	16	225	14	19	286
		Minimum	14	174	3	12	205
		Average	15.3±0.1	216.2± 3.8	6.6±0.5	15.6±0.2	247.2± 3.8
2	22	Maximum	17	548	11	20	579
		Minimum	14	349	2	15	385
		Average	15.5±0.1	445.8±10.6	5.4±0.4	16.8±0.2	478.1±10.4
3	1		14	960	7	14	988

[1] Prepupal period included in larval period.

TABLE 9.—*Summary of pupations, mortalities, and sex ratios of the 1931 brood of the sugar-beet wireworm reared at constant temperatures of 70° and 80° F., Alhambra, Calif.*

REARED AT 70° F.

Item	Pupations and larval mortalities		Sex ratio	
			Males	Females
	Number	*Percent*	*Percent*	*Percent*
Pupations:				
1931, 1-year cycle	6	12		
1932, 2-year cycle	26	52	52.4	47.6
1933, 3-year cycle	2	4	0	100.0
1934, 4-year cycle	6	12	33.3	66.7
Total	40	80	47.0	53.0
Larval mortality:				
1931	9	18		
1932	0	0		
1933	1	2		
1934	0	0		
Total	50	100		

REARED AT 80° F.

Item	Pupations and larval mortalities		Sex ratio	
			Males	Females
	Number	*Percent*	*Percent*	*Percent*
Pupations:				
1931, 1-year cycle	20	40		
1932, 2-year cycle	22	44		
1933, 3-year cycle	1	2		
Total	43	86		
Larval maturity:				
1931	4	8		
1932	3	6		
1933	0	0		
Total	50	100		

The 50 individuals reared at 70° F. hatched in the period March 17 to 23 from eggs deposited between February 22 and 28, 1931. As might be expected, the average duration of the various periods was very similar to that obtained in the 1931 series reared in the basement at a slightly lower average temperature. In comparing the rate of pupation with that of the latter group, it was found that with the exception of the third and fourth years the percentages were lower than those recorded for the basement-reared series.

Of unusual occurrence was the recovery of a prepupa on February 8, 1932. This specimen pupated on February 17 and transformed to adult on March 23. All remaining individuals pupated normally in the different years.

In this group the duration of the egg stage ranged from 18 to 29 days and the pupal period from 16 to 26 days.

The 50 larvae held at a constant temperature of 80° F. had hatched on March 10 and 11 from eggs deposited during the period February 22 to 24, 1931. Apparently this temperature was especially favorable for larval development. The larval mortality was also low, totaling 7, or 14 percent. Most of the pupations in the first year occurred later than usual, in October and November, thus extending the length of the larval period to an average of 216 days as compared with the averages of 159.7 and 171.3 days for individuals reared in the basement during the same year (table 3). Starting on February 22 in 1932, larvae pupated spasmodically throughout the spring and summer

until September 8. These abnormal pupations shortened the average length of the larval period for the 2-year-cycle specimens to 445 days, whereas for the basement-reared larvae averages of 527.4 and 520.5 days were recorded. The 1 specimen continuing to 1933 completed 23 observed [9] molts, finally pupating on October 25 after 960 days in the larval stage. Both the egg and pupal periods were shortened considerably, the former ranging in duration from 14 to 17 days and the latter from 12 to 20 days.

In the group held at 70° F. and in the 1931 basement series pupations occurred over a period of 4 years, whereas at 80° all but one of the larvae had completed development or succumbed at the end of the second year. This shows that the higher temperature in the cabinet held at 80° tended to accelerate development, while at a constant temperature of 70° the rate of pupation and the duration of the larval periods were more in accord with the results obtained when specimens were reared in the basement at variable temperatures ranging from a mean of 71° to 68° in the first and later years. The daily variation in the basement was from 3° to 8° with a seasonal variation of from a minimum of 50° in November to a maximum of 90° in July. Both these extremes occurred in 1931.

EFFECT OF DIFFERENT KINDS OF FOOD ON RATE OF DEVELOPMENT

Since the sugar-beet wireworm is not restricted to any one food it was decided to determine the effects of different kinds of food on the rate of its development. A series of 150 larvae that had hatched between April 23 and 28, 1933, was divided equally into 3 groups and fed individually as follows: Group 1 larvae were fed 1 lima bean, group 2 larvae 1 kernel of corn, and the larvae in group 3, 10 kernels of wheat each, at monthly intervals. All larvae were confined in salve cans and held in the basement under identical conditions, except for food. It was observed at each examination that neither the corn, nor the wheat, nor the lima bean had been entirely consumed, so apparently a surplus of food was available at all times. The results of this study are summarized in table 10.

TABLE 10.—*Effect of different foods on the rate of development of the sugar-beet wireworm*

Item	Pupation and mortality data when indicated food was supplied monthly					
	1 lima bean		1 kernel of corn		10 kernels of wheat	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Pupation:						
1933, 1-year cycle	0	0.0	0	0.0	1	2.0
1934, 2-year cycle	36	72.0	44	88.0	42	84.0
1935, 3-year cycle	0	.0	3	6.0	3	6.0
Total	36	72.0	47	94.0	46	92.0
Continuing as larvae to 1936	5	10.0	1	2.0	3	6.0
Larval mortality, 1933–35, inclusive	9	18.0	2	4.0	1	2.0
Total	50	100.0	50	100.0	50	100.0

[9] Possibly 5 of the earlier molts were missed.

Owing to the heavier mortality only 72 percent of the original number pupated the second year in the lima-bean group, as compared with 88 and 84 percent in the corn and in the wheat groups, respectively. There was only one pupation the first year, that in the wheat-fed group. A summary of the pupations to the fall of 1935 shows the corn group with the highest pupation percentage, wheat next, and lima beans third. A few individuals in each group continued as larvae into 1936. Although the experiment was on too small a scale for basing definite conclusions, the results indicate that there is probably little if any difference in the rate of development of the sugar-beet wireworm on the three kinds of food. It is difficult to say whether the large mortality in the lima-bean group was due to the use of this type of food or was the result of improper handling.

The size of the resulting adults would indicate that both corn and wheat were far superior to lima beans as food for wireworms, since 10 males that had been fed on corn during the larval stages averaged in weight 41 mg. each, and 10 fed on wheat 47 mg., as compared with 32 mg. for a like number of adult males that had been reared on lima beans. The females were heavier, averaging 70, 66, and 56 mg. each in the corn, wheat, and lima bean groups, respectively.

SIZE OF WIREWORMS IN RELATION TO AGE AND TIME OF PUPATION

It was observed that the larvae which hatched on May 21, 1930, and had been confined in a flowerpot and fed corn at intervals, varied in length when examined 7 months later on January 1, 1931. As many entomologists have used length as a basis for estimating the age of elaterid larvae, it was deemed advisable to separate 30 of these into 2 equal groups measuring 6 and 12 mm. in length, respectively. These were confined individually in salve cans and fed 6 kernels of wheat monthly. The number from each group that completed development in 1931 and 1932 was practically the same except for one less 3-year-cycle individual in the 12-mm. group. The length of the larval period for the 2-year-cycle individuals in the 6-mm. group averaged 467 days as compared with 458 days for the 12-mm. group. For those completing developments in 3 years the averages were 835 and 842 days in the 6- and 12-mm. groups, respectively The proportion of sexes in the 6-mm. group was 50–50, and in the 12-mm. group 60 and 40 percent males and females, respectively. The results indicate that the length of larvae has no significant relation to the time of pupation, nor can it be used as a criterion for estimating age.

QUANTITY OF FOOD CONSUMED BY LARVAE AT DIFFERENT STAGES OF GROWTH

To determine the number of wheat kernels eaten monthly, and when the least and when the most serious damage could be expected in the field, eight larvae that had hatched on April 15, 1932, were confined in individual containers and supplied with six kernels of wheat at each weekly examination. The inspection of wheat at such frequent periods made it possible to determine accurately whether or not each kernel had been destroyed.

As shown in figure 18 the number of kernels eaten monthly varied according to the changes in temperature. Above 70° F., larvae were

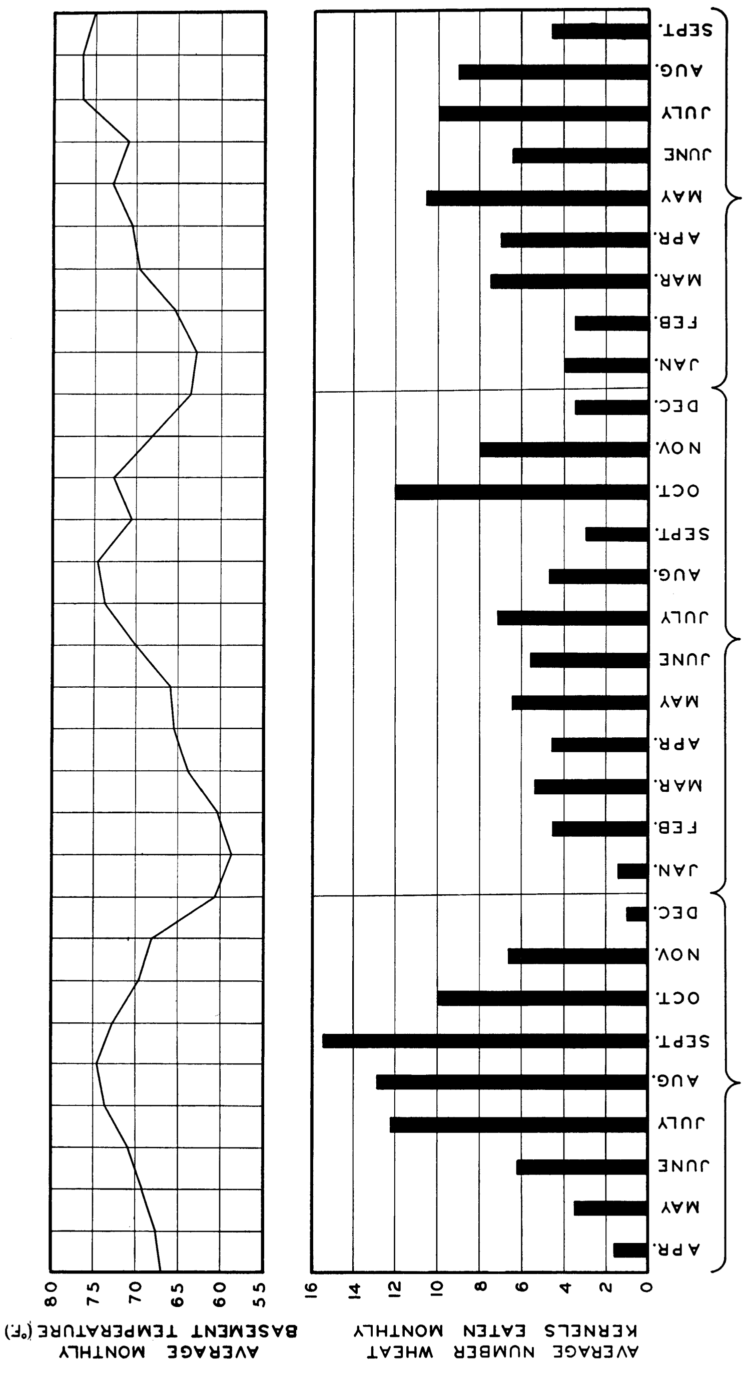

FIGURE 18.—Average numbers of wheat kernels eaten monthly during the life of a group of sugar-beet wireworms, with the mean basement temperatures, Alhambra, Calif., 1932–34.

exceedingly active, eating on an average from 6.1 to 15.4 kernels monthly. The lowest average was 1 kernel when the temperature averaged 60.5°. The greatest numbers of kernels were eaten by larvae, 3, 4, and 5 months old, during the months of July, August, and September, although it had always been thought that first-year larvae were incapable of doing much injury. In view of these results, however, they are undoubtedly responsible for a large share of the damage to vegetable crops planted in the fall.

The number of wheat kernels consumed by the 2-year-cycle larvae, all of which matured as males, ranged from 99 to 119 and averaged 106. Of the 2 larvae completing development in 3 years, the male ate 209 and the female 228 wheat kernels.

MOLTING

To obtain records of the molting of larvae of *Limonius californicus*, newly hatched larvae were placed singly in tightly stoppered 1- by 3-inch glass tubes with a thick plaster of paris bottom. These fitted tightly into holes provided in a large plaster of paris block. To insure an optimum moisture within the containers, the block was wetted at 3- or 4-day intervals. The food consisted of a small piece of the starchy portion of a corn kernel which had been left soaking overnight. The containers were examined on alternate days for molts and to replenish the food supply. A binocular microscope was necessary until the third instar was reached, but after this the larvae were of such size that the cast skins could be detected with the naked eye.

During the first 2 or 3 months the larvae were extremely delicate and readily susceptible to attacks by fungi; also, a heavy mortality resulted when the containers became either too dry or overmoist. After the fourth instar the larvae were transferred to 1-ounce salve cans containing 60-mesh soil and three or four kernels of moist wheat. By sifting the fine soil through a 60-mesh screen the cast skins could easily be detected. Additional food and new soil were provided at each weekly examination.

NUMBER AND DURATION OF INSTARS

The number of larval instars in the case of 9 sugar-beet wire worms completing development in the second year ranged from 10 to 13 (table 11). The number of instars would have been considerable less had development been completed in 1 year, or more if they had matured in 3, 4, or 5 years. Of a series of 25 larvae hatched in 1930, and which had been fed individually 1 kernel of wheat monthly, 1 larva continued to and died in 1934 after completing 22 molts. Another of the same series which pupated in 1934 completed 19 molts. Owing to difficulty in locating the earlier molts in this series the first 5 or 6 were missed, so it is possible that these larvae, which were reared under adverse conditions, had undergone from 25 to possibly 30 molts. There appears to be no relation between the number of instars and the sex of the resulting adult, since 1 specimen that completed development in 10 instars was a female and the 1 with 13, a male.

TABLE 11.—*Duration, in days, and number of instars of 9 sugar-beet wireworms reared at Alhambra, Calif., 1933–34, which completed development in 2 years*

Date of hatching, in 1933	Time spent by larvae in the specified instars													Length of larval stage	Sex
	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth	Eleventh	Twelfth	Thirteenth		
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	
May 21	44	27	10	26	27	52	128	62	57	46	-----	-----	-----	479	Female.
Apr. 5	27	33	28	29	16	20	43	147	65	63	61	-----	-----	532	Do.
Apr. 21	23	21	26	25	42	59	49	99	48	52	75	-----	-----	519	Male.
Apr. 5	29	28	39	36	21	27	16	65	99	48	52	60	-----	520	Female.
Do	21	34	33	29	17	19	43	36	128	48	52	63	-----	523	Do.
Apr. 21	32	23	34	22	26	27	32	49	99	48	63	68	-----	523	Do.
Apr. 20	27	21	25	21	18	26	27	52	128	62	68	49	-----	524	Male.
May 21	42	21	23	21	27	16	36	128	62	38	53	41	-----	508	Do.
Apr. 21	28	27	26	35	48	16	65	82	51	42	43	53	21	537	Do.
Average	30.3	26.1	27.1	27.1	26.9	29.1	48.8	80.0	81.9	49.7	58.4	55.7	21	518.3	
Maximum	44	34	39	36	48	59	128	147	128	63	75	68	21	537	
Minimum	21	21	10	21	16	16	16	36	48	38	43	41	21	479	

The length of each individual stadium depends primarily upon the temperature and the quantity of food available. At high temperatures larvae are very active, feeding voraciously and growing rapidly, but when the temperature drops, their activity and growth are retarded.

Observations were made on the growth of the same larvae that furnished the data for table 11, and the average length of the wireworm and width of the head capsule were recorded during each instar period as shown in table 12. For comparison the head-capsule width as computed by Dyar's law are also given.

TABLE 12.—*Length of larvae and size of head capsule of the sugar-beet wireworm in each instar*

Instar	Average length of larvae	Width of head capsule		Date of first molt	Date of last molt
		Average observed	Calculated		
	Mm.	*Mm.*	*Mm.*	*1933*	*1933*
First	2.7	0.274	0.274	Apr. 26	July 4
Second	3.3	.353	.343	May 30	July 31
Third	4.4	.422	.429	June 30	Aug. 15
Fourth	6.4	.544	.536	July 23	Sept. 5
Fifth	9.5	.648	.670	Aug. 10	Oct. 2
Sixth	13.8	.820	.838	Sept. 5	Nov. 23
					1934
Seventh	17.3	1.23	1.05	Oct. 2	Mar. 31
Eighth	21.0	1.35	1.31	Nov. 23	June 1
				1934	
Ninth	23.8	1.62	1.64	Mar. 31	July 28
Tenth	24.4	2.00	2.05	May 18	Sept. 12
Eleventh	25.5	-----	-----	Aug. 8	Sept. 22
Twelfth	26.0	-----	-----	Sept. 7	Oct. 11

During the period of the first 6 instars between April 5 and November 23 the larvae increased from their initial length of 2.7 mm. to an average of 13.8 mm., indicating that growth was exceptionally rapid during this period. This is also confirmed by the records of kernels

eaten (fig. 18), which shows that the largest quantity of food was consumed during the first year of larval life, especially during the months of July, August, September, and October. The duration of the instars was also shorter, ranging from an average of 26.1 to 30.3 days. With a drop in temperature during the winter and with less feeding the latter part of the first and during the second year, the average duration of the seventh and succeeding instars was lengthened. Molting continued very irregularly in 1934, causing considerable overlapping of molting dates and a wide variation between the maximum and minimum records. With the longer intervals between instars the length of the larvae increased in proportion until the maximum of 26 mm. was reached.

Owing to the rupturing of the exuviae directly in back of the head, considerable difficulty was experienced in obtaining accurate measurement of the head capsules, especially in the later instars. For this reason measurements were discontinued after the tenth instar. McDougall (*5*) in a recent paper reported similar difficulty with *Lacon variabilis* Cand., and found that measurements of the ventral mouth parts were more dependable in determining larval instars. A study of the observed head-width measurements as completed, however, indicates that these are in close agreement with the theoretical dimensions calculated by the application of Dyar's law.

SUMMARY OF DEVELOPMENTAL STUDIES OF WIREWORMS IN SALVE CANS

As shown by the data in various rearing experiments in which different quantities and kinds of food were used, the larval life of the sugar-beet wireworm is extremely variable, ranging from 5 or 6 to 53 months in duration. Of larvae that hatched on the same date and were fed the same kind and quantity of food, some pupated early and some later in the same year while others continued in the larval stage for several years. Often larvae 2 or 3 years of age would delay pupation until late in October, whereas larvae that were maturing in 1 year pupated earlier, in August or September of the same year. The factors governing the length of larval life are difficult to determine. Apparently temperature cannot be considered, as all individuals were reared in the basement under similar conditions of temperature. Nor is soil moisture a factor, as the optimum of 14 percent was closely adhered to when the soil was replenished in the salve cans at each monthly examination. The food was treated the same, usually soaked in water over night before being used the following day. Evidently different kinds of food are not concerned, as irregular pupations also occurred when lima beans and corn were used.

Table 13 shows the average durations of the larval period of 1,479 individuals reared in salve cans, and which matured in from 1 to 5 years. Owing to the late hatching of the larvae in 1929 and 1930, none of these completed development during the first year; in addition, the average life span of these larvae was shortened as compared with others that had hatched earlier in their respective seasons.

TABLE 13.—*Average duration of the larval period of sugar-beet wireworms, which matured in from 1 to 5 years when reared in salve cans, Alhambra, Calif., 1929–35*

Year series started	1-year cycle		2-year cycle		3-year cycle		4-year cycle		5-year cycle	
	Records	Average larval period	Records	Average larval period	Records	Average larval period	Records	Average larval period period	Records	Average larva period
	Number	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*
1929	0	------------	22	464.9	14	830.8	2	1,167.5	0	------------
1930	0	------------	266	485.5	108	843.1	7	1,218.0	3	1,589.7
1931	50	170.6	285	523.8	12	889.4	5	1,258.6	0	------------
1932	3	162.3	146	517.4	59	882.2	4	1,263.5	0	------------
1933 [1]	8	177.6	474	497.2	11	870.6	0	--------------	0	------------
Total or average	61	171.1±1.0	1,193	502.8±3.4	204	857.8±4.4	18	1,233.8±5.3	3	1,589.7±1.1

[1] 12 specimens continued as larvae to 1936.

In all cases the larval periods of the individuals developing into females averaged slightly longer than those of the larvae that developed into males. In the 2-year-cycle group 407 male larvae averaged 506 days in the larval stage as compared with an average of 509 days for 386 female larvae. The average duration of larval life for 48 males that matured in the third year was 861 days, and for 66 females 871 days. In the fourth year the average larval period was 1,225 days for 4 males, and 1,239 days for 8 females.

The numbers of sugar-beet wireworms reared in salve cans completing development each year during the period 1929 to 1935, inclusive, are shown in table 14. As previously stated, the absence of 1-year-cycle individuals in 1929 and 1930 was due to the late hatching of the larvae.

TABLE 14.—*Numbers and percentages of sugar-beet wireworms reared in salve cans completing their development in different numbers of years during the period 1929–35*

Year series was started	Individuals completing development in—										
	1 year		2 years		3 years		4 years		5 years		Total
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
1929	0	0.0	22	57.9	14	36.8	2	5.3	0	0.0	38
1930	0	0	266	69.3	108	28.1	7	1.8	3	.8	384
1931	50	14.2	285	81.0	12	3.4	5	1.4	0	0	352
1932	3	1.4	146	68.9	59	27.8	4	1.9	0	0	212
1933 [1]	8	1.6	474	96.1	11	2.2	0	.0	0	0	493
Total	61	4.1	1,193	80.7	204	13.8	18	1.2	3	.2	1,479

[1] 12 specimens continued as larvae to 1936.

There appears to be considerable variation in the percentages of individuals pupating in the different years. Especially was this true in the 1931 series, which had 14 percent maturing in the first year, and in the 1933 series, which had a pupation percentage of 96.1 in the second year. Apparently the high temperatures that prevailed throughout the spring and summer of 1934 stimulated larval feeding and increased the number of pupations as shown. In the third year the percentage maturing ranged from 2.2 in the 1933 series to 36.8 in the 1929 series.

The latter also had the highest percentage of maturing individuals in the fourth year.

Temperatures in the basement during the period of these rearing studies ranged from a monthly mean of 57.9° F. in January to 79.4° in July of 1931. The lowest daily minimum was 50° on November 24, 1931, and the highest maximum was 90° F., recorded on July 26, 1931.

OUTDOOR REARING STUDIES

For outdoor rearings unglazed drainage titles were used as cages (fig. 19). These were made by cementing two 6-by-12-inch drainage tiles end to end. They were set vertically in the ground 23 inches

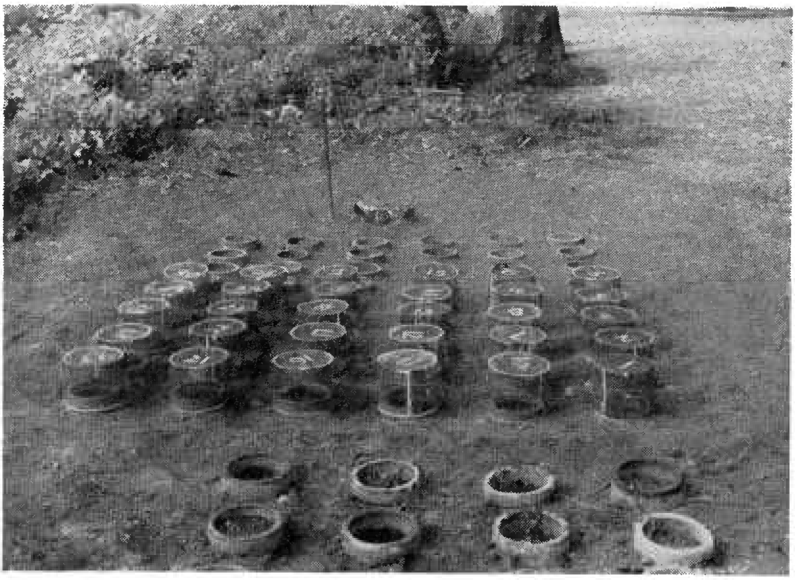

FIGURE 19.—Unglazed tile cages used for outdoor rearing, showing screen tops in position, Alhambra, Calif.

deep so that 1 inch remained above the surface for the attachment of screen cages. To prevent the escape of the larvae one-half inch of plaster of paris was poured into the bottom of each tile cage and allowed to harden. Soil of a sandy loam texture was taken from infested fields and screened and then placed in the cages and fumigated with carbon disulfide. Fine-mesh screen tops were attached prior to the emergence period to prevent possible oviposition by stray elaterid adults. Twenty-five small larvae were put in each cage. They were first fed wheat, but as they grew older their diet was changed to corn. Usually 15 to 20 kernels were provided at intervals of 6 weeks during the spring and summer and every 2 months during the winter, when their activity lessened. The moisture content of the soil was kept as near the optimum as possible by frequent irrigation. It was necessary to remove and sift the soil in the different series after transformation, to remove either the 1-, 2-, or 3-year-cycle adults present. In 1931 the cages were taken up and the soil pushed out so none of the larvae were injured. In later years a trowel was

used to remove the soil, which caused some larval injury as noted under handling mortality in the different years. Recording thermometers were used to record the temperature at the 4-, 8-, and 12-inch depths. Further details regarding equipment and methods of rearing sugar-beet wireworms in outdoor cages are explained by the author in another article (*8*).

The life-history studies outdoors in 1931 were based on the activities of 750 larvae that hatched in May and were confined in 30 tile cages. The examination of all cages in the fall of 1931 resulted in the finding of 2 adults (males) that had completed development after slightly more than 5 months in the larval stage. Over 61 percent of the total larvae were found missing, leaving 288 individuals continuing into the second year. The second examination in November 1932 showed that 8 percent of the original number of larvae had matured for a 2-year cycle and that 28.8 percent had succumbed. Of the 12 larvae remaining, 5 matured in 1933 for a 3-year cycle and 7 died or were eaten.

The proportion of sexes for all years totaled 55.3 percent males and 44.7 percent females. During the 3 years a total of 683, or 91 percent, of the larvae either died from natural causes or were the victims of cannibalism. This large mortality, expecially in 1931, may be attributed to the high soil temperatures, which on July 26 reached a maximum of 110° F. at the 4-inch level, 96° at 8 inches, and 88° at the 12-inch depth. The mean soil temperatures at all depths were considerably higher than those recorded during the first year in the brood studies of 1932 and 1933.

The 1,025 larvae used in the tile-cage studies in 1932 were segregated into 3 groups according to the time of their hatching, group 1 having hatched between April 1 and 15, group 2 between April 15 and 23, and group 3 between May 2 and 6.

The first examination, in November 1932, showed that the number completing development the first year decreased according to the time of hatching, from 18.1 percent in the early-hatching group 1 to 2.7 and 1.1 percent in groups 2 and 3, which hatched later. Dissections showed that the sex ratio of these individuals was 63.6 percent of males and 36.4 of females. The mortality was highest (98.9 percent) in the group hatching late in the season and lowest (64.6 percent) in the early-hatched group. A total of 808, or 78.8 percent, of the larvae were found to be missing. Of the 119 larvae removed from the cages, 18 were injured, leaving only 101 for observation in 1933.

In that year 9.9 percent of the original number matured in group 1 and 3.5 percent in group 2 for a 2-year cycle. No larvae remained in group 3. The proportion of sexes of these individuals showed females slightly in excess. Only one larva in each of groups 1 and 2 continued into 1934 for a possible 3-year cycle.

In summarizing the number completing development in all groups, it was found that 9.6 percent of the larvae matured in 1932 for a 1-year cycle and 5.8 percent in 1933 for a 2-year cycle. The sex ratio of the adults was in the proportion of 54.9 and 45.1 percent males and females, respectively. Over 84 percent of the larvae used were found missing or were injured. Mean soil temperatures were high during the life of the 1-year-cycle individuals and lower where development required 2 years for completion.

Studies of larval development outdoors in 1933 were based on the activities of 2,000 larvae that had also been segregated according to early, intermediate, and late hatching dates, and placed in 80 tile cages. The larvae in the respective groups had hatched between April 12 and 21, between April 29 and May 10, and between May 12 and 19.

The examination on November 1, 1933, further substantiated the results obtained in the 1932 series, mainly for the reason that the greater percentage of larvae that matured for 1-year cycle were found in the early hatched group. Although there was only a few weeks' difference in elapsed time between hatchings, 5.9 percent of the larvae matured in the early hatched group as compared with 1.1 percent in the intermediate and none in the late hatched group. Only 21.1 percent of the 1-year-cycle adults were females, indicating that female larvae, with few exceptions, require a longer feeding period to complete their development. The mortality during the first year was the lowest recorded, ranging from 42 percent in groups 1 and 2 to 33.3 percent in group 3. The total mortality was 815, or 40.7 percent of the original number. A total of 95, or 4.7 percent, of the larvae in all groups were injured during the process of removing them from the cages, leaving 1,019 larvae for examination in 1934.

On completion of the 1934 examination on November 1, it was found that 21.4 percent of the larvae had matured in group 1, 16.8 percent in group 2, and 20.7 percent in group 3, for a 2-year cycle. Of these 44.5 percent were males and 55.5 percent females. The mortality in all groups totaled 588, or 29.4 percent. Six of the 34 remaining larvae were injured, leaving 28 to be returned to the cages. Of these 21 matured in 1935 for a 3-year cycle and 7 succumbed.

A summary of all groups showed that 3.5 percent of the larvae matured in 1933 for a 1-year cycle, 19.8 percent matured in 1934 for a 2-year cycle, and 1.0 percent in 1935 for a 3-year cycle. Of the 489 individuals that matured, 44.5 percent were females. The mortality totaled 75.4 percent, being slightly lower than that recorded in previous years. There was a difference of only 2° F. in the soil temperatures at all depths in the 1-year-cycle groups, and a difference of 0.2° during the second year.

Table 15 gives the summary of the life-history experiments in tile cages during the period 1931 to 1935, inclusive. As was the case in the salve-can rearings, the greater number of larvae that matured during the first season was found in the early hatched and the least in the later hatched groups. A similar decrease was noted for the larvae completing development the second season. Although the tile-reared larvae were in constant competiton for food, they had a greater percentage of individuals maturing the first year than did the larvae confined individually in salve cans. It is possible that soil temperatures, which averaged from 4° to 5° F. higher than in the basement during the season, may have been the principal factor responsible for the difference in the percentages obtained. A further comparison shows that the majority of the tile-reared larvae completed development in 1 and 2 years, only a few continuing to the third year, whereas the greater percentage of the salve-can-reared larvae matured in 2 and in 3 years, some even continuing for 4 or 5 years before reaching maturity.

TABLE 15.—*Summary of life-history studies of the sugar-beet wireworm in tile cages, Alhambra, Calif., 1931–35*

Item	Group 1, early hatched		Group 2, intermediate		Group 3, late hatched		Total	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1-year cycle:								
Larvae in tile cages at start	1,550	100.0	1,000	100.0	1,225	100.0	3,775	100.0
Mortality during first year	759	49.0	591	59.1	733	59.8	2,083	55.2
Larvae recovered first year	641	41.3	392	39.2	488	39.8	1,521	40.3
Adults recovered first year	150	9.7	17	1.7	4	.3	171	4.5
2-year cycle:								
Larvae injured by handling first year	48	3.1	47	4.7	18	1.5	113	3.0
Larvae returned to cages first year	593	38.2	345	34.5	470	38.4	1,408	37.3
Mortality during second year	300	19.4	218	21.8	325	26.5	843	22.3
Larvae recovered second year	16	1.0	9	.9	23	1.9	48	1.3
Adults recovered second year	277	17.9	118	11.8	122	9.9	517	13.7
3-year cycle:								
Larvae injured by handling second year	5	.3	3	.3	0	0	8	.2
Larvae returned to cages second year	11	.7	6	.6	23	1.9	40	1.0
Mortality during third year	2	.1	1	.1	11	.9	14	.4
Larvae recovered third year	0	0	0	0	0	0	0	0
Adults recovered third year	9	.6	5	.5	12	1.0	26	.7

Of the 3,775 larvae used in the tile-rearing experiments, only 714, or 18.9 percent, completed development; 2,940, or 77.9 percent, were either the victims of cannibalism or died from natural causes; and 121, or 3.2 percent, were injured by handling.

Daily minimum and maximum soil temperatures were fairly consistent in the different years. From 1931 to 1935, inclusive, minimum daily temperatures at 4 inches ranged from 35° to 44° F.; at 8 inches, from 37° to 48°; and at 12 inches, from 41° to 50°. Maximum temperatures recorded at 4-, 8-, and 12-inch depths were 110°, 96°, and 88° in July 1931. In the period 1932 to 1935, inclusive, the highest daily temperatures at the 4-inch level ranged from 98° to 101°, at 8 inches from 91° to 92°, and at 12 inches from 87° to 88° F.

DURATION OF THE PREPUPAL PERIOD

To ascertain as accurately as possible the time of pupation in the salve cans, the larvae were examined at 3-day intervals beginning about the middle of July, and thereafter throughout the pupation period. At each such examination the larvae that had entered the prepupal stage, as indicated by inactivity, shortening of the body, and enlargement of the middle segments, were placed in a depression on top of the soil in salve cans, where they were observed daily until pupation.

The prepupae, as well as pupae, are delicate, helpless, and readily susceptible to attacks by a fungus and by bacteria. In many instances the prepupae would be completely entwined by strands of hyphae, but if these were removed or washed off, pupation would occur normally. Mites [10] also were frequently observed feeding on injured or dead specimens, apparently in the role of scavengers.

As shown in table 16, the earliest prepupa was obtained on May 29, in 1934, and the latest on October 23, in 1931. The yearly average duration of the prepupal period ranged from 6.4 days in 1931 to

[10] According to H. E. Ewing, these mites are migratory nymphs of some species of Tyroglyphidae, probably not parasitic.

9.4 days in 1933, and for the 4-year period the average was 7.6 days. Females remained in the prepupal condition for an average of 8.6 days as compared with 7.4 days for the males.

TABLE 16.—*Duration of the prepupal period of the sugar-beet wireworm in salve cans, Alhambra, Calif., 1931–34*

Year	Males and females				Males		Females	
	Prepupal dates: First	Prepupal dates: Last	Records	Average length of period	Records	Average length of period	Records	Average length of period
			Number	*Days*	*Number*	*Days*	*Number*	*Days*
1931	July 18	Oct. 23	482	6.4				
1932	July 10	Oct. 15	394	8.5	126	7.4	107	8.9
1933	Aug. 15	Oct. 22	161	9.4	74	9.3	77	9.7
1934	May 29	Oct. 15	483	7.5	226	6.7	244	8.1
Total			1,520	7.6	426	7.4	428	8.6

THE PUPA

TIME OF PUPATION IN SALVE CANS

The time and duration of the pupal period during the 4 years 1931 to 1934 was obtained by combining the data from all pupations in the different rearing groups, regardless of the quantity or kinds of food. Individual records were then segregated according to the weekly period in which the pupation occurred. The temperature records included in the time of pupation were obtained by averaging the daily temperatures in the basement rearing room for each week. Temperatures for the duration of the pupal period consisted of an average of the daily mean temperatures in each week from the date of the first pupation to that of the last transformation to the adult.

The first pupation in 1931 occurred on July 22 and the last 98 days later on October 27 (table 17). The season was marked by the occurrence of unusually high temperatures both outdoors and in the basement, and this was undoubtedly responsible for hastening larval development and subsequently the beginning of the pupation period. Referring to figure 20 it is observed that two distinct peaks occurred, one during the weeks ended August 25 and September 1 and one for the week that ended September 22. Temperatures advanced sharply in the week preceding and during the time in which the first peak occurred, after which they declined and continued low during the period of the second peak. In the latter case it does not appear that temperatures were significant, as the rate of pupation increased rapidly even though temperatures were on the decline. The rearings in the salve cans showed that 4- and even 5-year-old larvae pupated late in September after the majority of the younger larvae had already entered the pupal stage, thus indicating that the first peak was not the result of pupations of older larvae. Sex identity also does not appear to be of any consequence, as both male and female pupations occurred irregularly throughout the season.

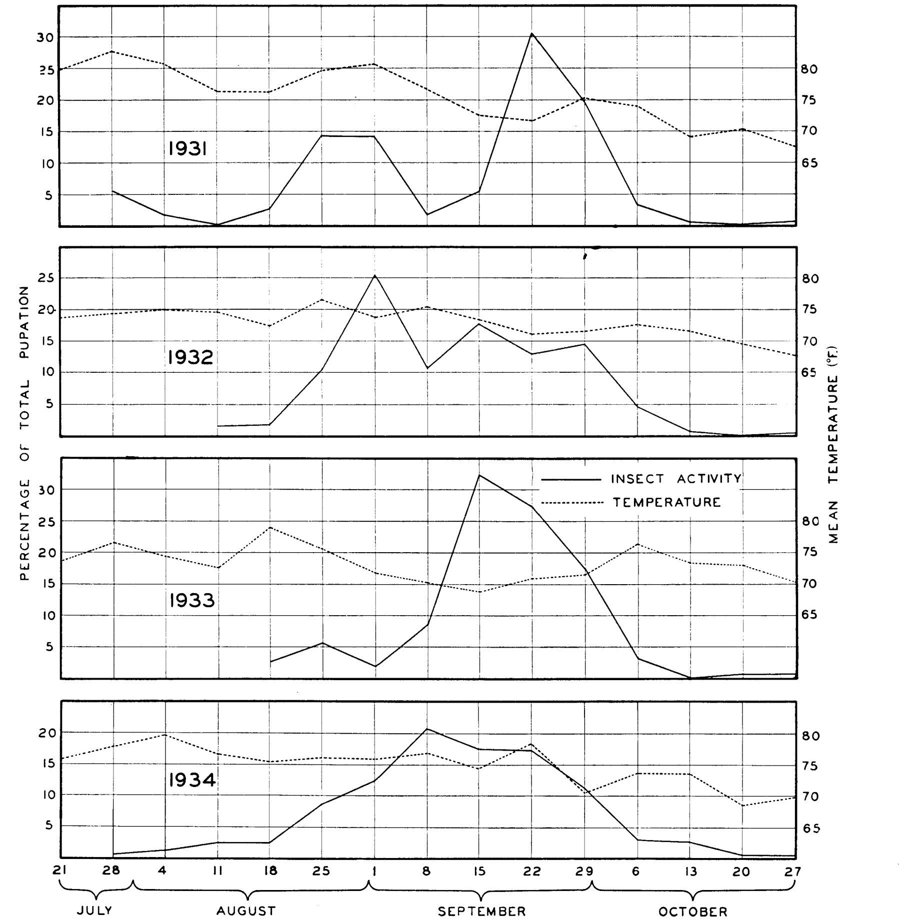

FIGURE 20.—Time and rate of pupation of the sugar-beet wireworm in salve cans as compared with mean basement temperatures of the laboratory, Alhambra, Calif., 1931–34.

TABLE 17.—*First and last records of pupation of the sugar-beet wireworm in salve cans, Alhambra, Calif., 1931–34*

Year	First record	Last record	Time from first to last record, inclusive
			Days
1931	July 22	Oct. 27	98
1932	Aug. 7	Oct. 24	79
1933	Aug. 16	Oct. 27	73
1934	June 13	Oct. 22	132

Low temperatures in the basement rearing room prior to the pupation period in 1932 not only retarded larval development but apparently delayed the beginning date of pupation to 2 weeks later than

in the previous years. The pupation period extended over a period of 79 days from August 7 to October 24, inclusive. The majority of pupations were recorded between August 26 and September 1, with a gradual decline starting on September 29 (table 18).

TABLE 18.—*Time of pupation of the sugar-beet wireworm in salve cans, Alhambra, Calif., 1931–34*

Pupated during week—	1931			1932			1933			1934 [1]			Summary, 1931-34	
	Pupations	Prroportion of total	Average mean temperature	Pupation	Proportion of total	Average mean temperature	Pupation	Proportion of total	Average mean temperature	Pupations	Proportion of total	Average mean temperature	Pupations	Proportion of total
	No.	*Pct.*	°*F.*	*No.*	*Pct.*	°*F.*	*No.*	*Pct.*	°*F.*	*No.*	*Pct.*	°*F.*	*No.*	*Pct.*
July 22–28	25	5.5	82.8	-----	------	74.3	-----	------	76.3	2	0.4	77.9	27	1.8
July 29–Aug. 4	8	1.7	80.7	-----	------	75.0	-----	------	74.4	6	1.1	79.8	14	.9
Aug. 5–11	0	0	76.3	6	1.5	74.7	-----	------	72.8	12	2.3	76.6	18	1.2
Aug 12–18	12	2.6	76.1	7	1.8	72.2	4	2.5	79.0	12	2.3	75.6	35	2.3
Aug. 19–25	65	14.3	79.6	40	10.3	76.4	9	5.6	75.7	46	8.8	76.0	160	10.5
Aug. 26–Sept. 1	64	14.1	80.6	98	25.2	73.8	3	1.9	71.9	64	12.3	76.0	229	15.0
Sept. 2–8	8	1.7	76.9	41	10.6	75.3	14	8.7	70.1	109	20.9	77.0	172	11.3
Sept. 9–15	25	5.5	72.6	68	17.5	73.3	52	32.3	68.9	91	17.5	74.5	236	15.5
Sept. 16–22	138	30.3	71.8	50	12.9	71.1	44	27.3	70.9	90	17.3	78.2	322	21.1
Sept. 23–29	90	19.8	75.1	56	14.4	71.3	28	17.4	71.4	58	11.1	70.4	232	15.2
Sept. 30–Oct. 6	15	3.3	74.1	19	4.9	72.6	5	3.1	76.2	15	2.9	73.8	54	3.5
Oct. 7–13	2	.4	69.1	2	.5	71.5	0	0	73.6	14	2.7	73.7	18	1.2
Oct. 14–20	1	.2	70.3	0	0	69.5	1	.6	73.1	1	.2	68.5	3	.2
Oct. 21–27	2	.4	67.5	1	.2	67.4	1	.6	70.2	1	.2	69.9	5	.3
Total	455	------	75.2	388	------	72.4	161	------	72.8	521	------	74.8	1,525	-----

[1] One specimen pupated on June 13, becoming an adult on July 2, and another pupated on July 13, becoming an adult on August 1.

In 1933 the first pupa was obtained on August 16 and the last 72 days later, on October 27. Temperatures were similar to those recorded in 1932, the average for the pupation period being only four-tenths of a degree higher than in the previous year. Nearly 60 percent of the pupations occurred during the 2-week period September 9 to 22.

The first pupation in 1934 occurred on June 13 and the next on July 13. These were the earliest pupation records obtained during the 4 years. Starting on July 26 the number increased gradually until the peak of pupation was reached in the week ended September 8. Nearly 67 percent of the pupations occurred during September. Weekly temperatures during the season were fairly high, averaging 74.8° F., which was four-tenths of a degree below the average obtained in 1931.

The summary for the 4 years was based on 1,525 individuals which pupated over a period of 14 weeks during the interval from July 22 to October 27. This summary shows that over 88 percent of the pupations occurred during the 6-week period August 19 to September 29. As the length of the pupal stage is approximately 21 days, ploughing for the destruction of pupae would then be most effective if done on 2 occasions, on or about September 5 and 25.

TIME OF PUPATION IN THE FIELD

The data on the time of pupation in the field were based largely on the records obtained when making population and depth studies at intervals during the summers of 1931, 1932, and 1933.

In 1931 two newly transformed adults were recovered at the 9-inch depth in a barren field near Temple, Calif., on July 31. As the average length of the pupal period is approximately 21 days, these individuals probably pupated on or about July 10. In 1932 the first pupa was taken on August 6. They were very abundant on a cornfield near El Monte and in tile rearing cages on August 30. Probably the most unusual and unaccountable discovery was the finding of a pupa on December 27, 1932, in a corn plot adjacent to the laboratory. Records for 1933 show a prepupa recovered on July 3 near Temple. This specimen pupated in the basement on July 10 and transformed to an adult on July 31. Of nine pupae taken in the same area on July 10 the first adult was obtained on July 21, and the remainder between July 26 and August 3. Though meager, these records indicate that pupation in the field begins early in July, the majority of pupations probably occurring during August and September, and the last about the middle of October.

DURATION OF THE PUPAL PERIOD IN SALVE CANS

The duration of the pupal period in salve cans during the years 1931 to 1934, inclusive, appears in table 19. These data are based on the same numbers of individuals shown for each week in table 18.

TABLE 19.—*Duration of the pupal period of the sugar-beet wireworm in salve cans, Alhambra, Calif., 1931–34*

Pupated during week—	1931			1932			1933			1934			1931–34 pupal period	
	Pupal period		Average mean temperature	Pupal period		Average mean temperature	Pupal period		Average mean temperature	Pupal period		Average mean temperature		
	Mean	Range		Mean	Range		Mean	Range		Mean	Range		Mean	Range
	Days	*Days*	°*F.*	*Days*	*Days*	°*F.*	*Days*	*Days*	°*F.*	*Days*	*Days*	°*F.*	*Days*	*Days*
July 22–28	16.7	15–19	79.8							16.0	16	78.6	16.3	15–19
July 29–Aug. 4	17.9	17–19	77.1							19.3	18–20	76.5	18.6	17–20
Aug. 5–11				22.1	20–24	74.2				18.8	18–20	76.0	20.4	18–24
Aug. 12–18	15.1	14–16	79.3	18.8	16–20	74.8	20.2	19–21	73.4	19.2	18–20	76.1	18.3	14–21
Aug. 19–25	15.5	13–17	79.3	20.7	18–22	74–8	21.9	21–23	71.9	19.4	18–22	75.9	19.4	13–23
Aug. 26–Sept. 1	17.3	14–20	75.8	21.6	16–24	73.4	24.0	24	70.1	19.1	18–21	76.5	20.5	14–24
Sept. 2–8	19.8	18–21	73.4	22.7	21–24	72.6	24.4	23–25	70.4	19.8	17–22	75.0	21.7	17–25
Sept. 9–15	19.3	18–20	73.3	23.7	21–26	71.6	23.1	21–24	71.9	20.2	18–22	74.3	21.6	18–26
Sept. 16–22	19.0	15–22	73.4	24.2	17–27	71.5	21.9	20–26	73.3	21.6	17–24	73.7	21.7	15–27
Sept. 23–29	20.3	16–23	72.1	24.6	22–27	70.7	21.3	19–23	74.0	22.1	18–25	71.5	22.1	16–27
Sept. 30–Oct. 6	21.4	19–25	70.0	25.7	24–33	69.9	22.1	21–23	73.7	23.2	22–24	71.4	23.1	19–33
Oct. 7–13	23.0	23	69.1	29.5	29–30	69.1				22.9	21–26	70.1	25.1	21–30
Oct. 14–20	23.0	23	69.6				26.0	26	69.3	24.0	24	69.0	24.3	23–26
Oct. 21–27	31.0	28–34	66.2	28.0	28	68.4	24.0	24	68.7	24.0	24	69.0	26.7	24–34
Average or range	18.7	13–34	74.9	23.3	16–33	72.2	22.6	19–26	72.3	20.5	16–26	73.8	21.4	13–34

The abnormally high temperatures in the basement rearing room during the period of pupation in 1931 shortened the pupal stage to an average of 18.7 days and a minimum of 13 days. The groups that pupated during the week of July 22–28 and the 2-week period between August 12 and 25 experienced the highest temperatures recorded during the 4-year period of these studies, and the average length of the period was from 15.1 to 16.7 days. A maximum of 34 days for the pupal period was recorded during the week that ended October 27 when the temperature dropped to a low of 66.2° F.

The seasonal average for the pupal period in 1932 was greater by seven-tenths of a day than the average of 22.6 days obtained in 1933. This slight variation may be attributed to the one-tenth of a degree difference in temperature, which averaged 72.2° in 1932 and 72.3° in 1933. The range in 1932 was from 16 to 33 days as compared with a range of from 19 to 26 days in 1933.

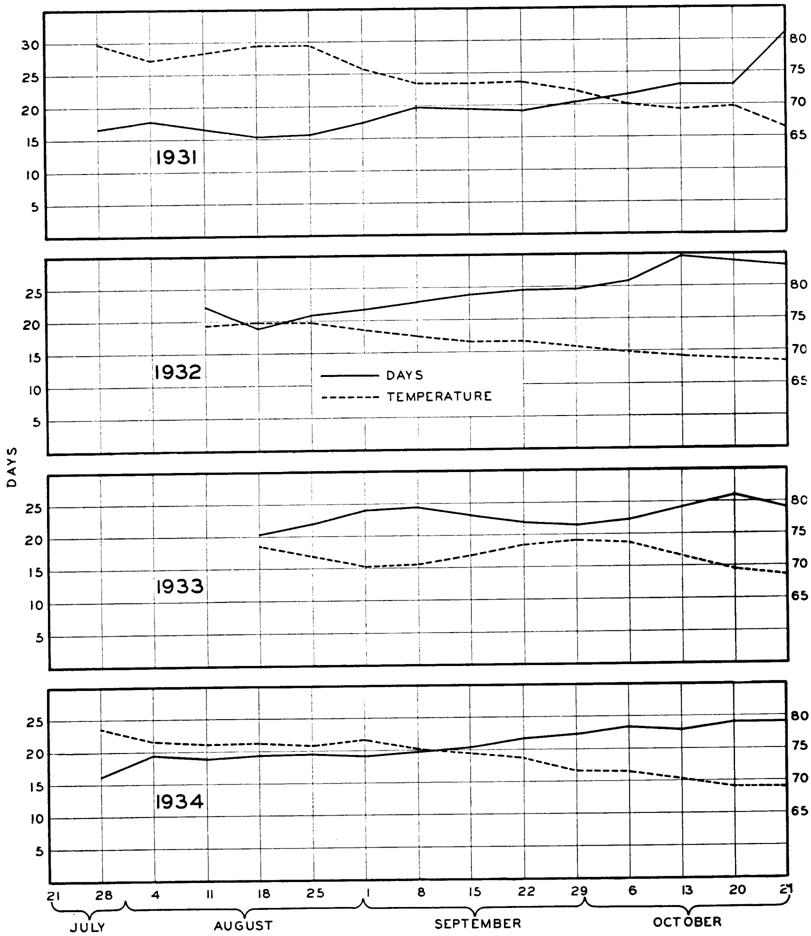

FIGURE 21.—Duration of the pupal period of the sugar-beet wireworm as compared with mean basement temperatures of the laboratory at Alhambra, Calif., 1931-34.

The pupal period in 1934 averaged 20.5 days and ranged from an average of 16 days for pupations occurring during the week ended July 28 to 26 days for pupations in the week October 7 to 13. Temperatures over the entire 14-week period averaged 73.8° F.

The summary shows that for all years the duration of the pupal period ranged from a minimum of 13 days to a maximum of 34 days and averaged 21.4 days. Figure 21 presents these data graphically for each year.

FACTORS AFFECTING THE DEPTH OF PUPATION

The depth at which larvae pupate is determined principally by the type of soil, its moisture content, the position of larval food prior to pupation, and soil temperature. Depth studies completed on August 30, 1932, in a cornfield near El Monte, Calif., showed that over 64 percent of the pupae were in the first 6 inches and the remainder between the 6- and 15-inch depths. The shallowness of these pupations was apparently due to the favorable temperature provided by the corn foliage, by an optimum soil moisture of about 12 percent at all depths, and by the presence of food near the soil surface. Siftings made on the following day in an adjoining fallowed field showed that the majority of the pupations had occurred between the 12- and 15-inch depths. In this case, however, the soil was exceedingly dry, ranging from a moisture content of 3.6 percent (dry weight) in the first 3 inches to 9 percent between the 12- and 15-inch depths.

DEPTH OF PUPATION IN OUTDOOR CAGES

The depth of pupation in outdoor cages was determined by confining 25 large larvae in each of 8 cages, early in March, so that there would be sufficient time for the larvae to feed and to orient themselves prior to pupation late in the summer. Corn was added at intervals of 6 weeks and the cages irrigated when necessary. A series of these cages were set up each spring during the years 1929 to 1932, inclusive. As the majority of pupations occur in September, the cages were removed and examined each year during this month.

The procedure consisted of first breaking the tile cages in half[11] and then forcing out and sifting each inch of soil after it had been sliced off with a large knife. The results for the different years are shown in table 20.

TABLE 20.—*Depth of pupation of the sugar-beet wireworm in tile cages, Alhambra, Calif., 1929–32*

Depth of pupae (inches)	1929		1930		1931		1932		1929–32	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
4					2	2.6			2	0.5
5	2	1.6			4	5.2	1	1.4	7	1.9
6	6	4.8	5	4.8	2	2.6	3	4.3	16	4.3
7	11	8.8	15	14.6	6	7.8	2	2.8	34	9.1
8	9	7.2	16	15.5	7	9.1	9	12.8	41	10.9
9	13	10.4	18	17.5	19	24.7	4	5.7	54	14.4
10	18	14.4	12	11.6	28	36.4	8	11.4	66	17.6
11	24	19.2	7	6.8	6	7.8	5	7.1	42	11.2
12	12	9.6	14	13.6	2	2.6	10	14.3	38	10.1
13	9	7.2	5	4.8			6	8.6	20	5.3
14	5	4.0	2	1.9			9	12.8	16	4.3
15	5	4.0	2	1.9	1	1.3	3	4.3	11	2.9
16	3	2.4	1	1.0			2	2.8	6	1.6
17	4	3.2	1	1.0			2	2.8	7	1.9
18			1	1.0			2	2.8	3	0.8
19	2	1.6	2	1.9			3	4.3	7	1.9
20	1	0.8	1	1.0					2	0.5
21										
22	1	0.8					1	1.4	2	0.5
23										
24			1	1.0					1	0.3
Total	125		103		77		70		375	
Minimum	5		6		4		5		4	
Maximum	22		24		15		22		24	
Mean	10.9		10.1		9.0		11.8		10.5	

[11] The outdoor cages consisted of two 6- by 12-inch drainage tiles cemented together end to end. A slight tapping around the cemented portion caused the halves to part readily.

Although considerable variation existed in the depths at which pupation occurred, there appeared to be only a slight difference in the mean depths in each of the 4 years.

The Adult

EMERGENCE IN THE FIELD

Data on the first and last appearances and on the abundance of the beetles in the field were obtained by sweeping alfalfa with an insect

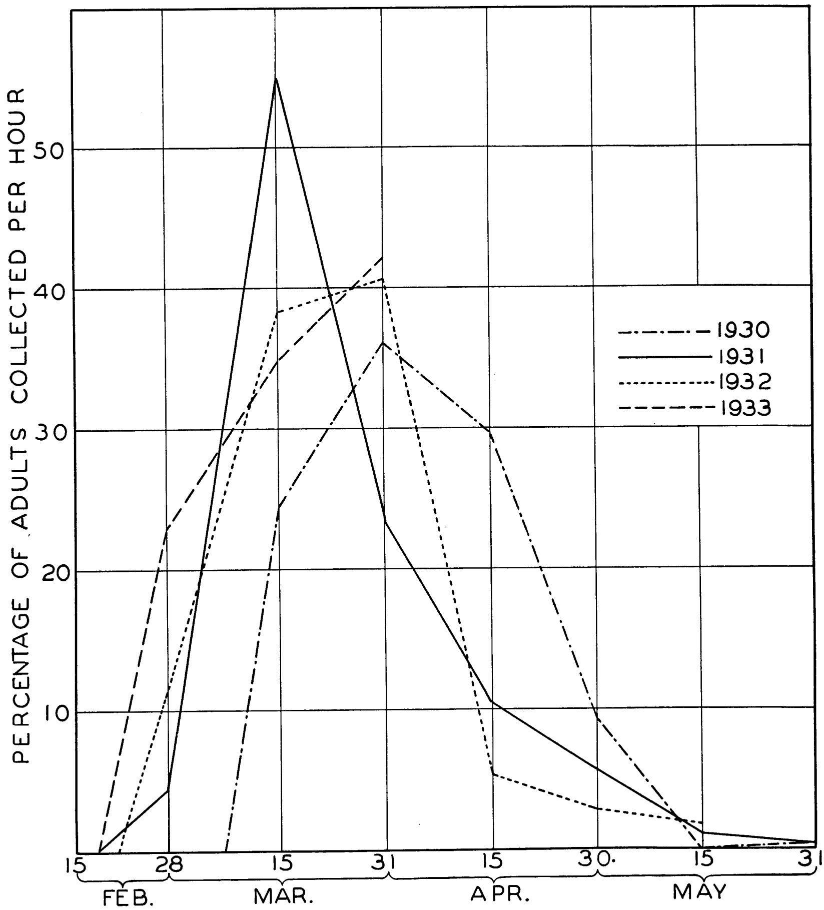

Figure 22.—Relative numbers of adults of the sugar-beet wireworm collected by sweeping in alfalfa fields at given intervals, Temple, Calif., 1930–33.

net on alternate days, if weather and time permitted, for a period of 15 minutes between the hours of 11 a. m. and 1 p. m. The results obtained during the seasons of 1930 to 1933 inclusive are shown graphically in figure 22.

In 1930 the first adults were collected at Temple, Calif., on March 8, and adults were active over a period of 82 days, until May 28. They were most abundant during the 2-week period ended March 31.

In 1931 emergence occurred earlier. Adults were taken on February 17 and in small numbers until March 1. The peak of collecting occurred between March 1 and 15, and the last adults were caught on May 26. On February 4, 1931, R. E. Barrett collected over 50 adults of *Limonius californicus* under codling moth bands on walnut trees near Ventura, Calif. It is believed that plowing in or near the groves had brought these adults to or near the surface, where they were exposed to higher and more variable surface temperatures. This may have been responsible for some activity, and with a period of lower temperatures they had crawled under the bands for shelter.

In 1932, in the vicinity of El Monte, adults first appeared on February 20 and were active over a period of 85 days, until May 14. Males were taken at Ventura on February 23; at Smeltzer, on alfalfa, and near Buena Park, on rhubarb blossoms, on February 24. The numbers of adults collected per hour at Temple during the 2 weekly periods ended March 15 and 31 averaged 214 and 227, respectively. These were the highest records obtained during the time of these studies. In Orange and Ventura Counties the peak of emergence, based on experiments with malva traps, occurred during the week ended March 25.

In 1933 Mr. Barrett collected two females and one male under moth bands on February 1 near Ventura. A number of males were swept from alfalfa near Temple on February 17. Females were collected near Pomona on February 21, under malva traps near El Monte on February 22, and on alfalfa near Temple on March 30. In the vicinity of Alhambra the adults were active over a period of 90 days, until May 17. Although the records for 1933 are incomplete, the peak of emergence probably occurred in the period March 16 to 31. Malva traps in Orange County yielded the greatest number of beetles during the week ended March 25, and in Ventura and Los Angeles Counties, during the week ended April 1. These field studies were discontinued after that date.

The summary for the 4 years (table 21) was based on the collection, by sweeping, of 8,199 beetles during a total of 80½ hours. Nearly 60 percent of these were collected in March. With the exception of 1931, the peak of adult collecting in the field occurred between March 16 and 31.

TABLE 21.—*Summary of the data on collections of adults of the sugar-beet wireworm in alfalfa fields, 1930–33*

Period	Collecting period	Adults collected		
		Total	Per hour	
	Hours	*Number*	*Average*	*Percent*
Feb. 17–28	12.0	779	64.9	13.4
Mar. 1–15	18.5	2,665	144.0	29.6
Mar. 16–31	21.0	3,089	147.1	30.3
Apr. 1–15	15.0	1,452	96.8	19.9
Apr. 16–30	7.0	194	27.7	5.7
May 1–15	4.0	18	4.5	0.9
May 16–31	3.0	2	.7	0.1
Total or average	80.5	8,199	101.8	----------

Mild temperatures during the winter of 1933–34 were responsible for an earlier increase in soil temperatures and for an emergence in 1934 beginning from 2 to 3 weeks earlier than in previous years. Males were taken on alfalfa near Artesia and El Monte as early as February 5 and females on February 21. In the heavier soils near Huntington Beach, males did not appear until February 12. The few records obtained by sweeping indicated that the adults were just as abundant as in previous years, there being no noticeable reduction in their number as a result of the exceptionally heavy rainfall, which totaled 19 inches during the period from December 13, 1933, to February 6, 1934. Malva-trap collections in Orange County, in 1934, showed that the peak of emergence occurred in the week ending March 18. In Ventura and Los Angeles Counties the largest numbers were collected between March 19 and 25.

In 1935, as a result of an exceptionally mild winter, males appeared on alfalfa in the sandy soil sections near El Monte in Los Angeles County on January 25. This was the earliest date of emergence to be recorded. At Huntington Beach, Orange County, males first appeared on February 1. No records are available for the females in either of these localities.

MONTHLY DEPTH RECORDS OF OVERWINTERING ADULTS

To ascertain the position of the overwintering adults in the soil each month prior to emergence, a group of tile cages (fig. 23) containing 25 large larvae each were set up in the springs of 1930, 1931, and 1932. The corn used as food was replenished at intervals of 6 weeks, and the moisture content of the soil was kept as near optimum as possible by frequent irrigations. Air temperatures and the temperatures in the soil at the 4-, 8-, and 12-inch depths were recorded during the experiment. Usually 4 to 6 tile cages, depending on the number of adults recovered, were removed and examined on the last day of each month beginning with August and continuing to February. To avoid the possibility of adults emerging prior to examination, the February group of cages was examined on February 20. The procedure was to break each cage in half on the cemented line and then force out an inch of soil at a time to be sliced off with a knife. The beetles and any larvae remaining were recovered by sifting each slice through a screen having 16 meshes per linear inch. Data on the depth of pupation were also obtained by these studies. The numbers of adults recovered at the various depths during the different months and years are shown in figure 24, and these data, together with the soil and air temperatures, appear in table 22.

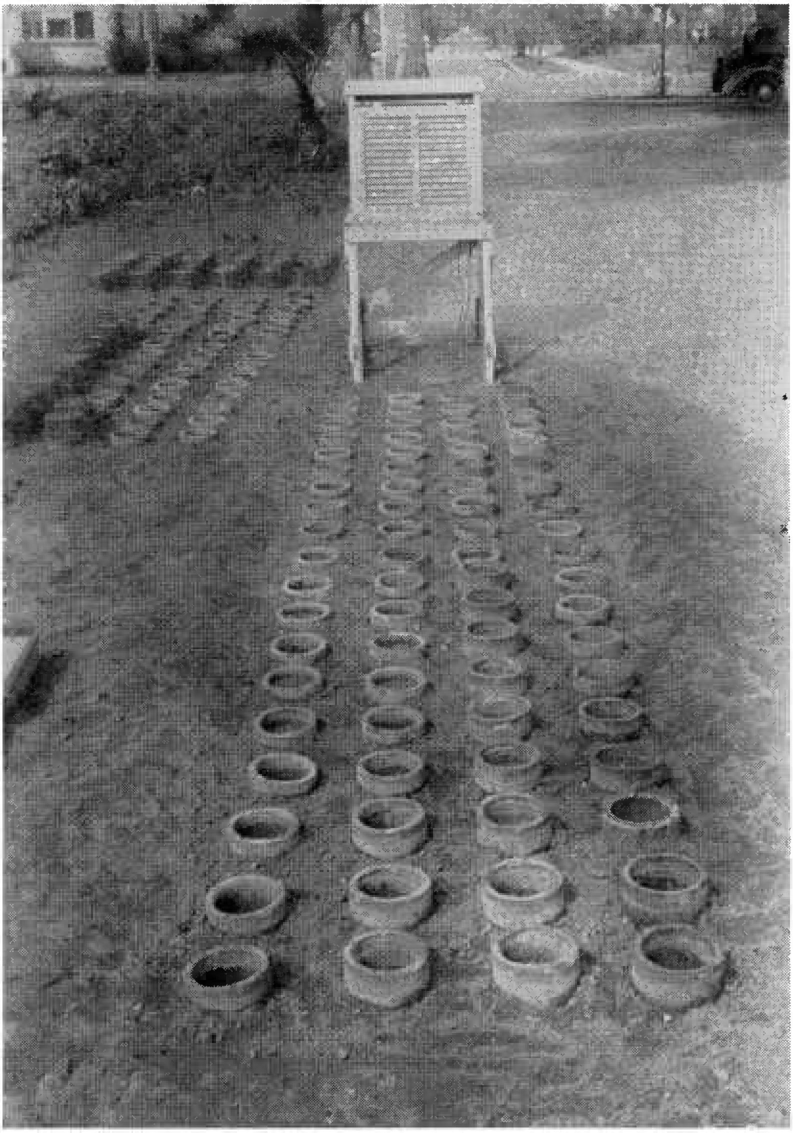

FIGURE 23.—Tile cages for rearing sugar-beet wireworms, and shelter containing instruments for recording air and soil temperatures, Alhambra, Calif.

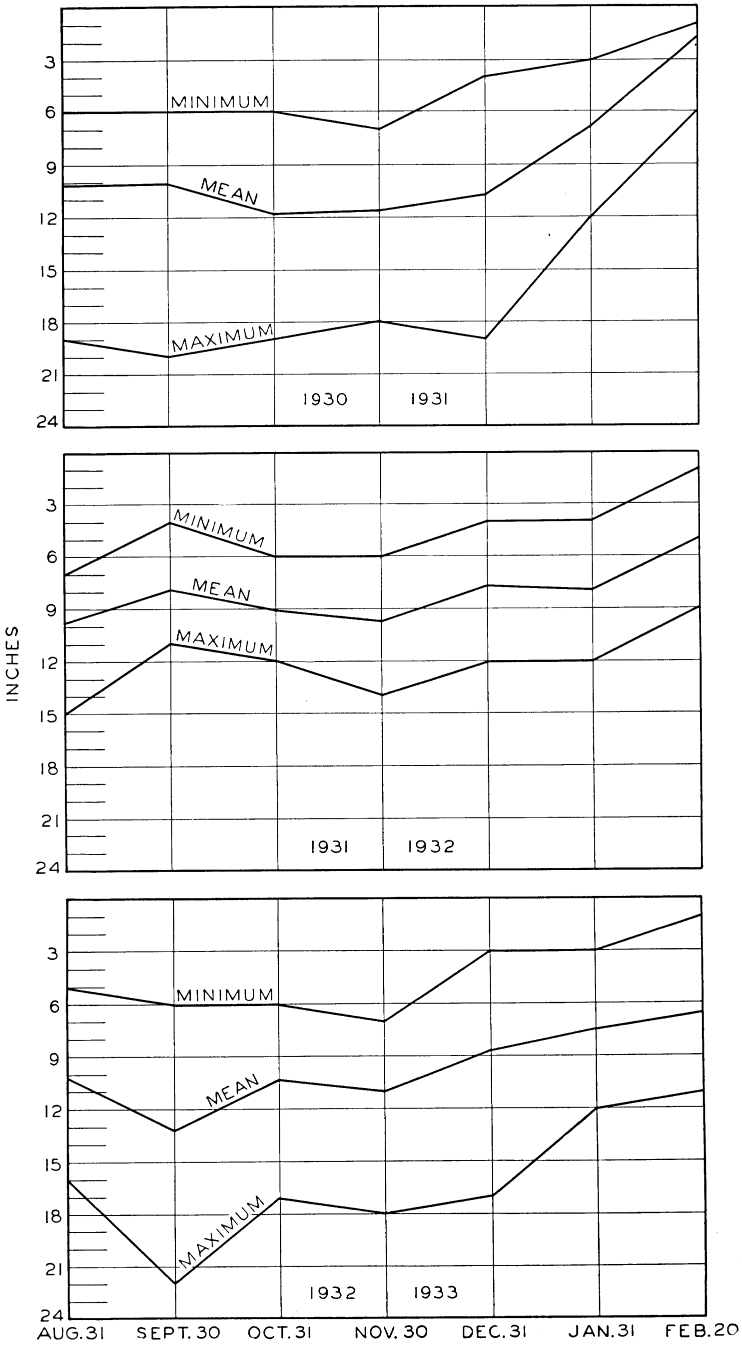

FIGURE 24.—Depths of adults of the sugar-beet wireworm in tile cages from time of transformation in the fall to emergence in the spring, Alhambra, Calif., 1930–33.

TABLE 22.—*Monthly records, showing depth of occurrence in the soil of overwintering adults of the sugar-beet wireworm in tile cages, Alhambra, Calif., 1930–33, inclusive*

FALL AND WINTER OF 1930-31

Date of examination	Adults recovered	Depth of adults in soil			Mean temperatures at—			Air temperature
		Minimum	Maximum	Mean	4 inches	8 inches	12 inches	
	Number	*Inches*	*Inches*	*Inches*	° *F.*	° *F.*	° *F.*	° *F.*
Aug. 31	46	6	19	10.2	78.5	75.1	78.3	73.5
Sept. 30	57	6	20	10.1	73.2	71.5	74.8	66.8
Oct. 31	78	6	19	11.9	68.6	64.7	66.6	64.0
Nov. 30	64	7	18	11.7	59.5	57.8	58.3	59.7
Dec. 31	81	4	19	10.8	49.9	48.9	47.4	51.4
Jan. 31	73	3	12	6.9	50.6	47.5	46.9	53.8
Feb. 20	51	1	6	1.8	56.3	52.9	54.0	56.2
Total or average	450				62.4	59.8	60.9	60.8

FALL AND WINTER OF 1931-32

Date of examination	Adults recovered	Minimum	Maximum	Mean	4 inches	8 inches	12 inches	Air temperature
Aug. 31	45	7	15	9.8	86.0	82.5	83.1	74.3
Sept. 30	32	4	11	7.9	78.0	75.8	77.8	68.0
Oct. 31	45	6	12	9.1	69.3	67.9	68.9	62.6
Nov. 30	73	6	14	9.8	54.1	52.8	54.6	53.1
Dec. 31	88	4	12	7.8	47.3	44.5	44.7	48.6
Jan. 31	70	4	12	8.0	46.0	43.3	45.6	47.6
Feb. 20	45	1	9	5.0	50.9	49.8	56.0	52.4
Total or average	398				61.6	59.5	61.5	58.1

FALL AND WINTER OF 1932-33

Date of examination	Adults recovered	Minimum	Maximum	Mean	4 inches	8 inches	12 inches	Air temperature
Aug. 31	32	5	16	10.2	78.7	78.3	78.8	73.0
Sept. 30	38	6	22	13.2	75.9	74.7	75.4	66.3
Oct. 31	33	6	17	10.3	66.9	66.6	67.2	62.2
Nov. 30	27	7	18	11.0	62.7	61.5	63.5	60.7
Dec. 31	29	3	17	8.6	49.1	47.7	53.2	48.4
Jan. 31	38	3	12	7.5	48.0	45.8	50.4	47.2
Feb. 20	29	1	11	6.5	55.4	54.8	54.7	50.0
Total or average	226				62.4	61.3	63.3	58.2

SUMMARY OF 1930-33, INCLUSIVE

Date of examination	Adults recovered	Minimum	Maximum	Mean	4 inches	8 inches	12 inches	Air temperature
Aug. 31	123	5	19	10.1	81.1	78.6	80.1	73.6
Sept. 30	127	4	22	10.5	75.7	74.0	76.0	67.0
Oct. 31	156	6	19	10.8	68.3	66.4	67.6	62.9
Nov. 30	164	6	18	10.7	58.8	57.4	58.8	57.8
Dec. 31	198	3	19	9.1	48.8	47.0	48.4	49.5
Jan. 31	181	3	12	7.5	48.2	45.5	47.6	49.5
Feb. 20	125	1	11	4.0	54.2	52.5	54.9	52.9
Total	1,074							

The beginning and rate of movement of the adults to the surface depend entirely on soil temperature. Significant changes in air temperature usually affect the soil temperature at the 4-inch depth in from 1 to 2 hours. At the 8- and 12-inch depths, however, the response may not be felt until late in the evening, or on the following day, depending on the degree of the air-temperature changes.

The data obtained in 1930 showed that there was but slight variation in the mean depths of occurrence of the adults between August and December, inclusive. It is observed also that the minimum and maximum depths are fairly consistent each month. The fact that

many of the adults were found intact in their pupal cells would indicate that but little movement surfaceward had taken place even as late as December. Therefore, the depth at which the adults were recovered in this period could be considered as their normal depth of pupation. Although mean soil temperatures for January at the 8- and 12-inch depths were lower than in the preceding month, air temperatures advanced sharply beginning on January 24, causing an increase in soil temperatures at all depths. Undoubtedly this sudden change was responsible for the movement of the adults from a maximum depth of 19 inches to within 12 inches of the surface. The average depth on January 31 was 6.9 inches. Air temperatures continued to rise during February, resulting in a substantial increase in soil temperatures at all depths, which accounted for the presence of all the adults in the upper 6 inches, and at an average depth of 1.8 inches on February 20. The first emergence of the adults occurred on February 24.

In 1931 both the mean and maximum depths of the adults were less in comparison with the previous and later years. This is difficult to understand, considering the fact that soil temperatures for August and September averaged considerably higher than for the same months in either of the other years, and that under such conditions pupation should occur at even lower depths. In this case probably the soil temperatures were not high enough to have had any effect on the larvae prior to pupation, or else, owing to the extremely warm summer, the larvae had become accustomed to the high temperatures that prevailed. A sharp drop in air and soil temperatures during November was followed by even cooler weather and subsequently lower soil temperatures during December and January. Although the results for the latter months showed the occurrence of the adults higher in the soil, it is believed that no movement surfaceward of these individuals had occurred. With a rapid rise of air and soil temperatures during February, the examination on February 20 showed that all beetles had moved from a maximum depth of 12 inches to within 9 inches of the surface, and that the average depth was 5 inches. Emergence in 1932 began on March 1.

In 1932, except for September 30, the records of the occurrence of the adults in the soil during the months of August to November, inclusive, were very similar to those for the same months in 1930. The soil and air temperatures were also about the same. The results show that the beetles were nearer the surface on December 31, even though soil temperatures at all depths were on a decline. This movement continued during January, when temperatures were even lower. On several occasions daily maximum air temperatures in December and January reached 78° and 83° F. This was responsible for a slight rise in soil temperatures and subsequent movement on the part of the adults, as shown.

As in previous years, air and soil temperatures at all depths during February 1933 increased rapidly, bringing some of the beetles to within 1 inch of the surface and giving an average depth of 6.5 inches on February 20. In the emergence cages adults appeared on the surface on that date.

These data indicate that adults generally remain in their pupal cells at an average depth of 10.5 inches until November 30. During December movement surfaceward begins even though the air and soil

temperatures at all depths are on the decline. In spite of still lower temperatures during January the adults continued to move surfaceward from an average depth of 9.1 inches at the first of the month to an average of 7.5 inches on January 31. A considerable increase in soil temperatures during February hastened their rate of movement and brought all adults to within 11 inches of the surface on February 20, when the average depth was 4 inches.

A check on the sex of the adults removed from the tile cages at various depths on January 30, 1933, showed that the average depth of the males in the soil was 5.4 inches as compared with 9.3 inches for the females (table 23). Examinations made on February 22 in both 1932 and in 1933 showed the mean depth of occurrence of the males to be 4 and 3.5 inches, whereas the females were 6.1 and 7.6 inches below the surface, respectively. An average of both years also shows that the female minimum, maximum, and modal depths of occurrence in the soil were greater than for the males. It is believed that the females require a higher temperature to stimulate activity and movement surfaceward. The results of these studies explain the earlier appearance of the males in the field, in tile cages, and under malva traps.

TABLE 23.—*Depth of occurrence of male and female adults of the sugar-beet wireworm in tile cages on Jan. 30 and Feb. 22, Alhambra, Calif., 1932 and 1933*

Item	Depth when examination occurred							
	Feb. 22, 1932		1933				Both years, Feb. 22	
			Jan. 30		Feb. 22			
	Males	Females	Males	Females	Males	Females	Males	Females
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Minimum	1	2	3	8	1	1	1	1.5
Maximum	9	9	9	12	9	11	9	10.0
Mean	4	6.1	5.4	9.3	3.5	7.6	3.8	6.9
Mode	1	9	6	9	1	10	1	9.5

EMERGENCE FROM TILE CAGES

Early in the summer of 1930 preparations were made for obtaining data on the emergence of adults during the next season. A group of the tile cages (fig. 19) used for outdoor rearing studies (p. 41) were used. Each tile was filled with sterilized sifted soil, and a small quantity of corn and 25 large larvae of *Limonius californicus* were buried between 6 and 12 inches deep. Larvae confined in this manner had sufficient time to feed and to orient themselves normally before entering the prepupal stage. Except for occasional irrigations and the attachment of 18-mesh, cylindrical, removable screen tops (fig. 19), no further care was required. During the emergence period the beetles were removed twice daily, usually at 12 m. and 5 p. m. Instruments enclosed in a standard Weather Bureau shelter were used to record the temperature of the air and of the soil at the 4-, 8-, and 12-inch depths. The results obtained in 1931 proved so satisfactory that larger series of cages were set up in the 4 succeeding years. A record of the number of larvae introduced and of the adults recovered each year appears in table 24.

TABLE 24.—*Number of larvae of the sugar-beet wireworm introduced and adults recovered from tile emergence cages, Alhambra, Calif., 1931–35, inclusive*

Item	1931	1932	1933	1934	1935	Total
Cages employed ... number	9	12	30	28	30	109
Larvae introduced ... do	225	300	750	560	750	2,585
Larvae that failed to pupate ... do	58	0	3	64	92	217
Larvae destroyed or died ... do	31	207	570	258	319	1,385
Emerged as adults ... do	136	93	177	238	339	983
Emerged ... percent	60.4	31	23.6	42.5	45.2	38

As the rate of emergence is governed by temperature, the data covering the years 1931 to 1935, inclusive, together with the mean soil temperature for each week at the 4- and 8-inch depths, are shown graphically in figure 25.

Emergence of the adults of the sugar-beet wireworm in 1931 began on February 24 and extended over a period of 38 days, until April 2. The peak of emergence occurred during the week ended March 12. It is probable that the slight increase in soil temperatures between February 12 and 19 furnished the stimulus for the appearance of the adults, for during the following week, when emergence started, a decline in the mean temperature is noted.

Beginning in 1932 a careful record was kept of the sex of all adults removed from the emergence cages (fig. 26). The first male emerged on March 1 and the first female on March 4. Males were more numerous during the first and second weeks but were surpassed by the females in the third week of the emergence period. The peak of emergence for both males and females occurred during the week ended March 19. Male emergence terminated on March 24 and female emergence on April 3. The beetles emerged over a period of 34 days.

In 1933, males first appeared on February 20 and females on February 28. The males again predominated during the first 2 weeks but were outnumbered by the females in the third and later weeks. The peak of emergence for the females was reached in the week ended March 19 and for the males the week following, March 20 to 26. Emergence extended over a period of 44 days, until April 4. The last female was collected on April 3.

Emergence in 1934 was not only early but also differed from that of previous years in that both males and females were taken on February 13. As in the past, males continued to outnumber the females in the first, second, and in this case even the third week. The peak of male emergence occurred between February 27 and March 5, and for the females during the period March 6 to 12. For both sexes together the peak of emergence was recorded during the week ended March 5. With the recovery of the last female on March 28 and a male on April 2, emergence in 1934 lasted over a period of 49 days.

In 1935 emergence of males and females began on January 30, reached a seasonal peak during the week ended March 19, and terminated April 4. The total period of emergence was 65 days. Both air and soil temperature means at all depths for December 1934 and January 1935 were the highest recorded during the 5-year period of these studies and apparently were responsible for this earliest appearance of the adults. Mean soil temperatures during the first 4 weeks

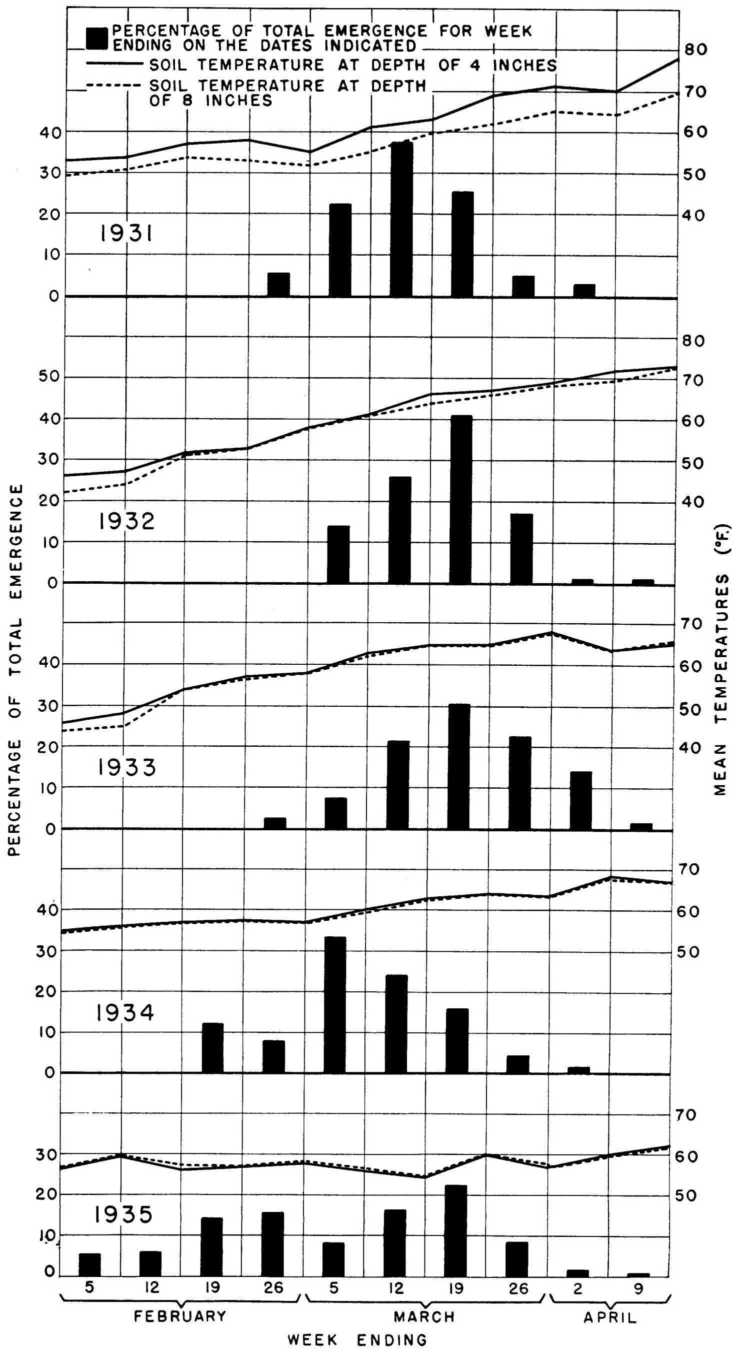

FIGURE 25.—Time and rate of emergence, by weeks, from tile cages of adults of the sugar-beet wireworm, Alhambra, Calif., 1931–35.

of the emergence period, terminating February 26, were in general similar to the temperatures obtained during the same weeks in previous years. Beginning on February 27, and continuing for the

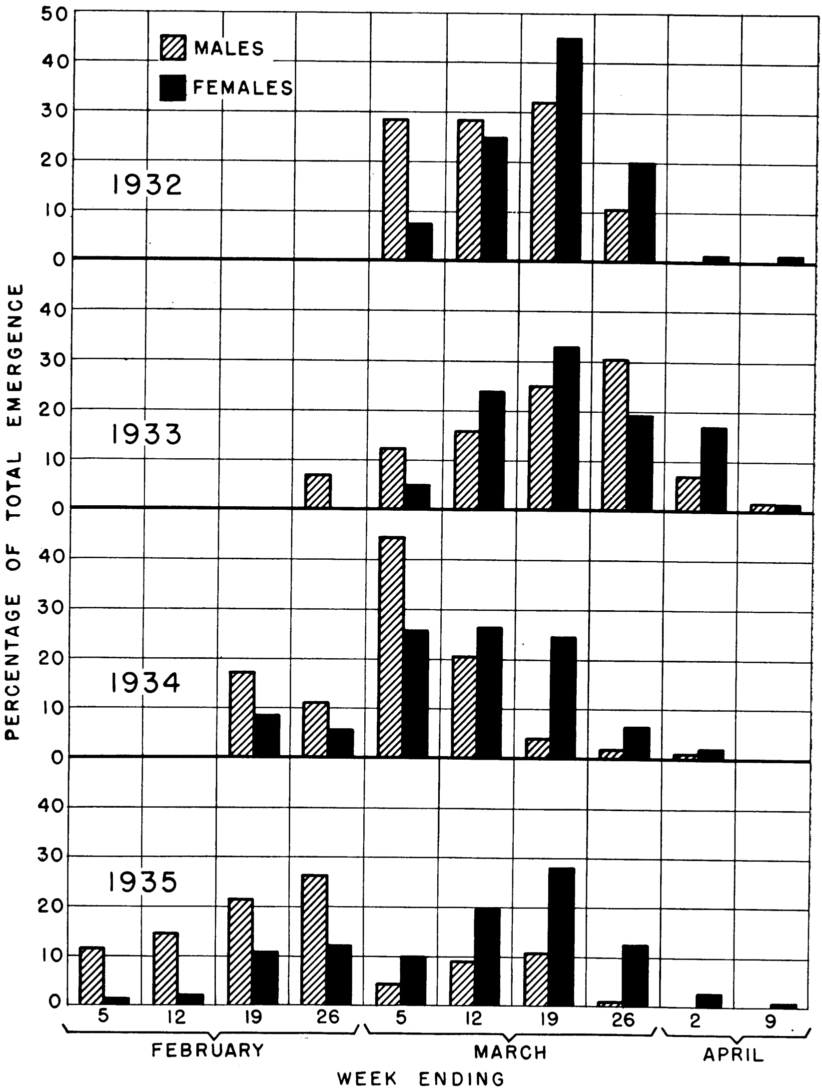

FIGURE 26.—Time and rate of emergence, by week, of males and females of *Limonius californicus* from tile cages, Alhambra, Calif., 1932–35.

remaining weeks of the emergence period, soil temperatures were unusually low, causing an extended emergence period, as shown.

Males were more abundant than females during the first 4 weeks, the situation being reversed during the fifth and remaining weeks of the emergence period. Males terminated their emergence on March 25 and females on April 4.

EFFECT OF SOIL TEMPERATURE ON BEGINNING OF EMERGENCE

A study of the mean soil temperatures for December and January at the 4-, 8-, and 12-inch depths during the period 1931–35 (table 25) reveals the fact that the date of first emergence is entirely governed by the temperature during these 2 months.

TABLE 25.—*Effect of soil temperatures in December and January on time of adult emergence of the sugar-beet wireworm in tile cages*

Season	Mean soil temperatures at—						Date of first appearance of—	
	4-inch depth		8-inch depth		12-inch depth			
	December	January	December	January	December	January	Males	Females
	°F.	°F.	°F.	°F.	°F.	°F.		
1931–32	47.3	46.0	44.5	43.3	44.7	45.6	Mar. 1	Mar. 4
1932–33	49.1	48.0	47.7	45.8	53.2	50.4	Feb. 20	Feb. 28
1933–34	53.0	53.4	53.8	53.7	54.5	53.8	Feb. 13	Feb. 13
1934–35	55.9	52.6	57.1	53.4	57.3	53.1	Jan. 30	Jan. 30

TIME OF DAY OF EMERGENCE

To determine the time of day that the adults emerge from the soil, collections were made daily at 2-hour intervals from 28 tile cages over a period of 36 days, from February 21 to March 28, 1934.

As shown in table 26, the heaviest emergence for both sexes occurred between 11 a. m. and 1 p. m. and the lowest between the hours of 3 and 5 p. m. Very few adults were found on the surface during rainy, cloudy, or cold days. Apparently a slight daily increase in temperature in the first few inches of soil is essential for emergence to occur. No emergence was noted after 5 p. m. or before 8 a. m.

TABLE 26.—*Record of the daily emergence of adults of the sugar-beet wireworm at 2-hour intervals from tile cages, Alhambra, Calif., 1934*

Hour of collection	Emergence			Proportion of total		
	Males	Females	Total	Males	Females	Total
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
9 a. m.	11	19	30	14.3	15.2	14.8
11 a. m.	13	24	37	16.9	19.2	18.3
1 p. m.	31	38	69	40.3	30.4	34.2
3 p. m.	19	36	55	24.7	28.8	27.2
5 p. m.	3	8	11	3.9	6.4	5.4
Total	77	125	202			

EMERGENCE BASED ON MALVA-TRAP COLLECTIONS

The results of the malva-trapping [12] experiments in a 3-acre infested field near El Monte, Calif., in 1933 revealed additional facts on the beginning and rate of male and female emergence in the field. These data, based on daily collections from 10 malva traps during the period from February 19 to April 30, are shown graphically in figure 27. The

[12] See footnote 4, p. 9.

daily mean air temperatures taken 3½ feet above the soil surface are also shown.

As usual, males were taken earlier, on February 19, and the first female on February 22. Males outnumbered the females 16 to 1 during the period February 19 to 28, and over 3 to 1 between March 1 and 15. From then on the females surpassed the males in numbers until trapping was terminated on April 30. The majority of females were collected during the period from approximately March 21 to April 5. The influence of temperature on the rate of emergence is well illustrated in figure 27. When high daily temperatures prevailed, the number of adults collected on the following days increased; and when temperatures declined, a decrease in their number is noted.

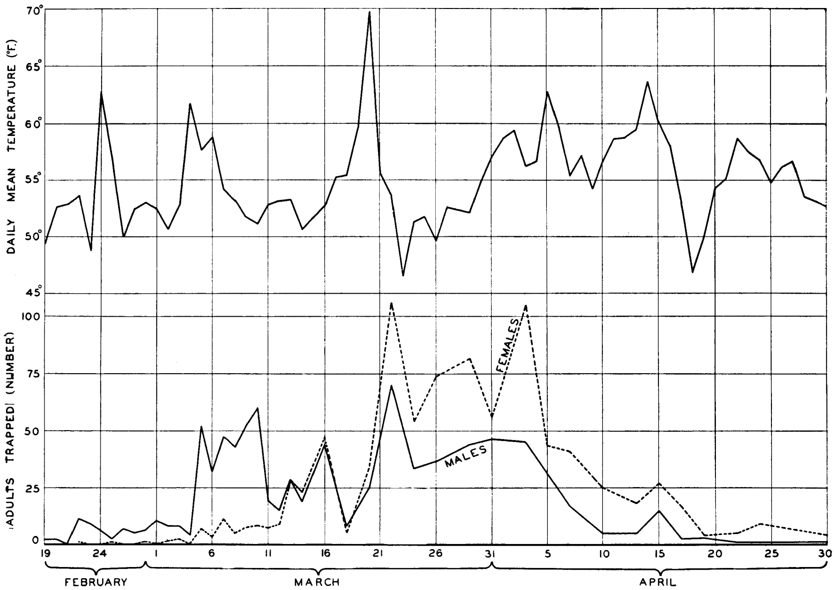

FIGURE 27.—Number of males and females of *Limonius californicus* captured daily in malva traps, with the daily mean air temperature, El Monte, Calif., 1933.

HIBERNATION OF ADULTS

Graf (*4, p. 33*) states that after the adults appear on the surface, a secondary hibernation takes place. This begins about the middle of February and continues to the middle of March. As his remarks are accompanied by the statement that the weather during the period was cold and cloudy with occasional showers, it is possible that this hibernation was only of one season's occurrence. During the period that these studies were conducted there were frequent rains and cold spells which lasted for several days. On these occasions the adults sought cover under clods and debris, but with warmer weather their activities were resumed. The cage-emergence records and field-collecting data reported herein show conclusively that a secondary hibernation does not exist. It shows that there is a gradual emergence of adults and that their numbers increase as the season progresses.

PROPORTION OF SEXES

SEX RATIO BASED ON ADULT EMERGENCE FROM TILE CAGES

The records of adult emergence from tile cages during the years 1932 to 1935, inclusive, showed that males outnumbered the females during the first 2 weeks in 1932 and 1933 and during the first 3 and 4 weeks in 1934 and 1935, respectively. The situation was reversed in the remaining weeks of the emergence period, but for the entire season of each of the 4 years the females considerably outnumbered the males. This preponderance of females each year was apparently due to the fact that only large (presumably mature) larvae were selected for use in the emergence cages, as these would be the most certain to pupate. As shown later (table 35), the weight of larvae which transformed to females averaged 91 mg., while those maturing as male adults averaged 57 mg., so most of the large larvae selected would naturally mature as females.

SEX RATIO BASED ON DISSECTION OF BEETLES COLLECTED UNDER MALVA TRAPS

The data on the sex ratio of the adults collected under malva traps in the years 1932 to 1934, inclusive, were based on the daily dissection of from 25 to 100 beetles from collections made in Los Angeles, Orange, and Ventura Counties.

In the Orange County field there was in 1932 a gradual increase from 36.6 percent females at the beginning of the season to 78.2 percent during the week ended April 8. Collecting in the Ventura field was begun 2 weeks later than in Orange County, during the week ended March 25. The female percentage was then 53.1 and by the end of the season had increased to 65.1 percent. For the entire season, the Orange County and Ventura fields averaged 70 and 54.2 percent females, respectively.

Adult trapping in 1933 began on February 19 in Los Angeles County and on March 5 in Orange and Ventura Counties. In Los Angeles County the percentage of females ranged from 5.9 for the week ended February 25 to 86.7 for collections made from April 23 to 29. The average for the season was 50.4 percent females. In both the Orange and Ventura County fields the percentage of females increased as the season progressed. Dissection of beetles from the former field showed an average of 74.2 percent, and for the latter field 48.9 percent females for the season.

In 1934 the traps were set out too late to catch the first males, and by the time trapping had begun females were already in the majority, the lowest percentage of females for the season being 55.2 in the Ventura field. The highest recorded was 100 percent in the week ended April 15, in Orange County. For the three fields the average percentage of females ranged from 65.5 in Ventura County to 80.8 in Orange County.

Table 27 presents a summary of the sex ratio based on the dissection of 10,056 beetles from all fields during 1932, 1933, and 1934.

TABLE 27.—*Summary of data pertaining to sex ratio of adults of Limonius californicus collected under malva traps, 1932–34*

Week ended—	1932				1933			
	Males	Females	Total	Females	Males	Females	Total	Females
	Number	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*
Feb. 25					32	2	34	5.9
Mar. 4					48	4	52	7.7
Mar. 11	19	11	30	36.7	527	325	852	38.1
Mar. 18	0	0	0	0	255	349	604	57.8
Mar. 25	273	317	590	53.7	251	460	711	64.7
Apr. 1	165	242	407	59.4	229	344	573	60.0
Apr. 8	382	746	1,128	66.1	234	461	695	66.3
Apr. 15	52	97	149	65.1	36	109	145	75.2
Apr. 22					16	78	94	83.0
Apr. 29					2	13	15	86.7
Total	891	1,413	2.304	61.3	1,630	2,145	3,775	56.8

Week ended—	1934				1932–34			
	Males	Females	Total	Females	Males	Females	Total	Females
	Number	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*
Feb. 25					32	2	34	5.9
Mar. 4					48	4	52	7.7
Mar. 11	230	560	790	70.9	776	896	1,672	53.6
Mar. 18	233	616	849	72.5	488	965	1,453	66.4
Mar. 25	269	790	1,059	74.6	793	1,567	2,360	66.4
Apr. 1	213	656	869	75.5	607	1,242	1,849	67.2
Apr. 8	68	173	241	71.8	684	1,380	2,064	66.9
Apr. 15	33	136	169	80.5	121	342	463	73.9
Apr. 22					16	78	94	83.0
Apr. 29					2	13	15	86.7
Total	1,046	2,931	3,977	73.7	3,567	6,489	10,056	64.5

SEX RATIO BASED ON SALVE-CAN AND TILE-CAGE REARINGS

A summary of the data concerning the proportion of sexes based on the dissection of 1,603 adults reared in salve-can and tile cages during the period from 1930 to 1934, inclusive, shows that the males greatly outnumber the females when development is completed in 1 year (table 28). For those maturing in 2 years the proportion is more even, but for those maturing in the 3-, 4-, and 5-year cycles a considerable increase in the percentage of females is noted. Except for the first year, for which no explanation can be offered, the figures showing the proportion of sexes in tile cages are comparable with those obtained in the salve cans.

TABLE 28.—*Proportion of sexes of sugar-beet wireworms of different maturing age reared in salve cans and tile cages, Alhambra, Calif.*

Period in larval stage (years)	Reared in salve cans				Reared in tile cages			
	Males	Females		Total	Males	Females		Total
	Number	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*	*Number*
1	13	1	7.1	14	179	85	32.2	264
2	412	392	48.7	804	173	216	55.5	389
3	43	63	59.4	106	2	3	60.0	5
4	6	12	66.7	18				
5	0	3	100.0	3				
Total	474	471	49.8	945	354	304	46.2	658

MATING

In the field mating usually takes place on the day of emergence between the hours of 9 a. m. and 3 p. m. Mating seldom occurs on cool, cloudy, or rainy days, or on days when strong winds prevail, but in favorable weather sexes emerging simultaneously from tile cages were observed to mate immediately.

In the laboratory, with temperatures ranging from 75° to 85° F., newly emerged or reared adults were taken in copulation at all hours of the day. Although males have been observed to mate several times with the same female, one mating is adequate to insure fertility during the life of the female.

PREOVIPOSITION PERIOD

As determined from 67 records (table 29), the duration of the preoviposition period for females reared in salve cans and tile cages, confined in the basement during the years 1931 to 1933, inclusive, was found to average 5.7 days, with a maximum of 14 and a minimum of 3 days. The length of the period for the adults reared in salve cans averaged 5.2 days, or 0.9 of a day less than the average obtained for the adults that had been reared in tile cages outdoors.

TABLE 29.—*Preoviposition period of adults of the sugar-beet wireworm reared in salve cans and tile cages and later confined either in the basement or in outdoor oviposition cages, Alhambra, Calif., 1931–34*

Year	Confined during preoviposition period in—	Total records	Preoviposition period: Maximum	Preoviposition period: Minimum	Preoviposition period: Average
REARED IN SALVE CANS IN BASEMENT					
		Number	*Days*	*Days*	*Days*
1931	Basement	18	8	4	4.6
1932	do	11	9	3	5.5
1933	do	5	8	6	6.8
Total or average		34	9	3	5.2
REARED IN TILE CAGES OUTDOORS					
1931	Basement	10	14	6	7.9
1932	do	10	6	3	3.8
1933	do	13	10	3	6.5
Total or average		33	14	3	6.1
REARED IN SALVE CANS AND TILE CAGES					
1932	Sun	9	17	6	11.2
1933	do	14	18	5	10.4
1934	do	13	20	5	11.6
1932	Shade	8	14	5	10.9
Total or average		44	20	5	11.0
Grand total or average		111	20	3	7.8

Averages obtained outdoors in the sun and in the shade during the seasons of 1932 to 1934, inclusive, are fairly consistent and probably are indicative of the normal length of the period in the field from

year to year. Soil-surface temperatures in the sunny and shaded localities varied widely in 1932, but this did not seem to have affected the length of the period to any great extent. The results indicate that the more constant temperatures, such as prevail in the basement, are more effective in shortening the preoviposition period than the wider daily variations which occurred outdoors.

An examination of all outdoor records in the sun showed that the length of the preoviposition period is governed by the date of adult emergence and becomes shorter as the season progresses. For instance, the length of the preoviposition period for females emerging between February 14 and 28 averaged 14.4 days. For those emerging between March 1 and 15 and between March 16 and 30 the averages were 10.3 and 8.5 days, respectively. Frequent dissections showed that egg development was more complete in the females emerging near the end of the season, thus substantiating the records shown.

On the basis of all outdoor studies the duration of the preoviposition period would average 11 days, with a maximum of 20 and a minimum of 5. This is of special significance when trapping measures against the adults are considered. It indicates that no deposition would be likely to occur during the first 5 days and but little thereafter up to the eleventh day after emergence.

Oviposition

TECHNIQUE USED IN OBTAINING OVIPOSITION RECORDS

In obtaining oviposition records, males and females that had been reared either in salve cans or in tile cages were confined immediately after mating in 1-ounce salve cans filled two-thirds full of fine soil containing approximately 12 percent moisture by weight. The soil was removed each day and washed through a 60-mesh screen until the first eggs were recovered. Thereafter, the soil was washed and the egg removed at weekly intervals until oviposition ceased. This same procedure was followed when outdoor oviposition cages were used. The cage container was filled with 60-mesh soil to within three-eighths of an inch of the top and placed in moist earth so that the soil, adults, and eggs deposited would not be subjected to desiccation. A series of these cages was set up in 1932 in an alfalfa plot to determine the effects of shade. Another series was exposed directly to the sun in 1932, 1933, and 1934. By the use of weekly-recording thermometers soil-surface temperatures in both localities were obtained each season.

OVIPOSITION IN THE BASEMENT

Oviposition records in 1931 were based on the activity of 18 females that had been reared in salve cans and of 10 females reared in tile cages; in 1932, on 11 females reared in salve cans and 10 reared in tile cages; and in 1933, on 5 reared in salve cans and 13 in tile cages.

OVIPOSITION BY SALVE-CAN-REARED ADULTS

The salve-can-reared females in 1931 were mated from February 14 to 19, inclusive. The length of the preoviposition period had ranged from 4 to 8 days and averaged 4.6 days. Owing to comparatively low temperatures, which averaged 61° F., oviposition was extended over

79 days, from February 17 to May 6, inclusive. The duration of the oviposition period of individual females ranged from 16 to 75 days and averaged 39 days. Over 61 percent of the eggs were laid during the first week and 12.6 percent in the second week. One female oviposited over a period of 11 weeks; the remainder completed egg deposition by the end of the eighth week. The number of eggs deposited ranged from 89 to 294 and averaged 191.2.

The females used in 1932 were taken in copulation during the period March 2 to 18, inclusive, and began laying eggs in from 3 to 9 days. The average length of the preoviposition period was 5.5 days and the range for the oviposition period from 8 to 35 days, averaging 25 days. Of the total eggs deposited, over 56 percent were laid during the first week and 25 percent more by the end of the second week. Individual egg totals ranged from 122 to 372, the average being 262.7.

In the 1933 rearings pairs 3, 4, and 5 were observed in copulation on March 31, 4, and 17, respectively, after having already mated on February 22. Whether this is of common occurrence is not known. The records show no appreciable difference in the number of eggs deposited or in the length of the oviposition period for observed second-mated pairs and those not so observed. The length of the preoviposition period for this group averaged 6.8 days, with a maximum of 8 and a minimum of 6. Owing to low initial temperatures only 34.7 percent of the total eggs were laid the first week, which was the lowest recorded for the first week during these studies. This was followed by the highest second and third week's productions for the basement series, 27.4 and 17.2 percent, respectively. Individual records of eggs deposited ranged from 397 to 543 and averaged 468.8. The length of the oviposition period ranged from 42 to 63 days and averaged 52.

OVIPOSITION BY ADULTS FROM TILE-CAGE REARINGS

The tile-reared females that emerged between March 6 and 31, 1931, were mated on the day of their emergence. First eggs were obtained on March 11 and the last eggs 52 days later, on May 2. The preoviposition period had averaged 7.9 days with an individual variation of from 6 to 14. The oviposition period ranged in length from 14 to 42 days and averaged 28.9. Individual egg totals ranged from 123 to 233, with an average of 177.3. Over 62 percent of the eggs were laid during the first week, 21 percent the second week, and the remainder in the following 4 weeks.

The longevities of the males and females in this group, living under a mean temperature of 63.5° F., averaged 23.3 and 43 days, respectively, as compared with averages of 43.1 and 54.8 days for the salve-can-reared males and females living under a mean temperature of 61°.

The 10 pairs reared in tile cages and ovipositing in 1932 emerged and mated between March 14 and 29. For this group the length of the preoviposition period averaged 3.8 days and that of the oviposition period 26.6. The range for the former was from 3 to 6 days and of the latter from 14 to 42. An average of 221.4 eggs were deposited; 62 and 24 percent of the total were laid in the first and second weeks, respectively. Temperatures in the basement during the activities of these adults averaged 68° F., which was slightly higher than usual.

The beetles of the tile-cage-reared group in 1933 were mated during the period March 5 to April 15 and began laying eggs from 3 to 10 days after mating. Oviposition continued over a period of 58 days,

from March 12 until May 8. The average length of the oviposition period was 29.6 days and the range from 14 to 49 days. The rate of egg production was comparable to that of other years, with 61.7 percent laid during the first week and 18.6 percent during the second week. Individual egg records ranged from 213 to 359, with an average of 273.7. The longevities of the tile-reared males and females living under a mean temperature of 64.8° F. averaged 23.6 and 42.8 days, as compared with 53- and 63.4-day averages, respectively, for the group reared in salve cans under a mean of 63.9°.

SUMMARY OF OVIPOSITION RECORDS OBTAINED IN BASEMENT

The numbers and percentages of eggs deposited weekly by females reared in salve-can and tile cages during 1931, 1932, and 1933 are shown in table 30 and graphically in figure 28.

TABLE 30.—*Summary of the numbers and percentages of eggs deposited at weekly intervals in the basement by salve-can and tile-reared adults of the sugar-beet wireworm, Alhambra, Calif., 1931–33*

Week of oviposition period	Eggs deposited weekly in—							
	1931				1932			
	18 females reared in salve cans		10 females reared in tile cages		11 females reared in salve cans		10 females reared in tile cages	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
First	2,119	61.6	1,115	62.9	1,622	56.1	1,375	62.1
Second	434	12.6	379	21.4	732	25.3	526	23.8
Third	264	7.7	98	5.5	415	14.4	190	8.6
Fourth	204	5.9	145	8.2	82	2.8	79	3.6
Fifth	259	7.5	32	1.8	39	1.3	18	.8
Sixth	49	1.4	4	.2			26	1.2
Seventh	38	1.1						
Eighth	55	1.6						
Ninth	11	.3						
Tenth	3	.1						
Eleventh	5	.1						
Total	3,441		1,773		2,890		2,214	
Average mean temperature	°F. 61.0		°F. 63.5		°F. 67.3		°F. 67.8	

Week of oviposition period	Eggs deposited weekly in—Continued							
	1933				1931–33			
	5 females reared in salve cans		15 females reared in tile cages		34 females reared in salve cans		35 females reared in tile cages	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
First	813	34.7	2,194	61.7	4,554	52.5	4,684	62.1
Second	643	27.4	662	18.6	1,809	20.8	1,567	20.8
Third	404	17.2	344	9.7	1,083	12.5	632	8.4
Fourth	152	6.5	182	5.1	438	5.0	406	5.4
Fifth	211	9.0	111	3.1	509	5.9	161	2.1
Sixth	37	1.6	54	1.5	86	1.0	84	1.1
Seventh	57	2.4	11	.3	95	1.1	11	0.1
Eighth	26	1.1			81	.9		
Ninth	1				12			
Tenth					3	.2		
Eleventh					5			
Total	2,344		3,558		8,675		7,545	
Average mean temperature	°F. 63.9		°F. 64.8		°F. 64.0		°F. 65.4	

It is noted that the females reared in tile cages deposited more eggs during the first week than did those reared in salve cans. This may be accounted for by the fact that the former emerged and mated later and oviposited over a slightly warmer period as shown by the average tem-

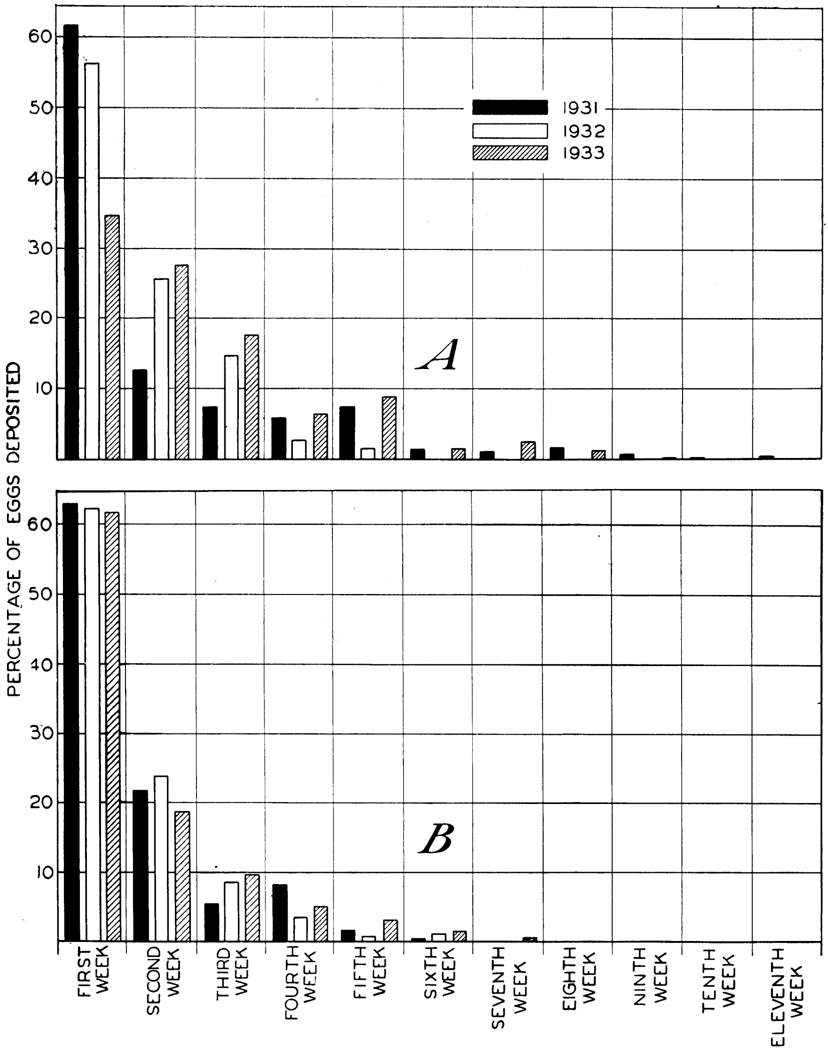

FIGURE 28.—Oviposition by adults of the sugar-beet wireworm in salve cans in the laboratory basement: *A*, By individuals that had been reared in the basement; *B*, by individuals that had been reared in tile cages outdoors. Alhambra, Calif., 1931–33.

peratures for the two groups during the different years. The decrease in the number of eggs deposited in 1933 during the first week in the salve-can-reared group was caused by a period of low temperatures which retarded oviposition considerably.

The totals of the oviposition records for the 3-year period show that 57 percent of the 16,220 eggs were laid during the first week, 20.8 percent the second week, and 10.6 percent during the third week after oviposition began. The shortest period was 5 weeks in 1932, and the longest extended to 11 weeks in 1931. The earliest oviposition in the basement was on February 17, and in outdoor cages in the sun on March 3.

OVIPOSITION IN CAGES EXPOSED TO THE SUN

Oviposition records outdoors in the sun in 1932 were based on the activities of three females reared in salve cans and mated on February 26 and of six tile-reared females which emerged and mated in the period March 4 to 21, inclusive.

The egg-laying period was marked by unusually high maximum soil-surface temperatures ranging from 107° to 118° F., which were responsible for the death of 3 males in the cages shortly after mating. The preoviposition period ranged from 6 to 17 days, with an average of 11.2 days. First and last eggs were obtained on March 3 and April 25, respectively. This group deposited 1,684 eggs, the average per female being 187.1 and the maximum 559, which was not exceeded outdoors during the period of these studies. Over 52 percent of the eggs were deposited the first week and 24 percent the second week. As a result of the high maximum temperatures the adult life was shortened, in comparison with the records obtained in the following years, to an average of 17.9 days for the males and 39.1 days for the females. Although free adults in the field would disperse to shaded localities if temperatures such as shown in these studies prevailed, the results indicated that even under such adverse temperatures females will survive readily and deposit most or all of their eggs.

Oviposition records for 1933 outdoors in the sun were based on the performance of five females reared in salve-can cages and nine females reared in tile cages that mated in the period February 22 to March 30, inclusive.

From a female taken in copulation on February 22 first eggs were obtained on March 9. Owing to the favorable temperatures oviposition continued later than usual, to May 18. The length of the preoviposition period decreased as the season advanced, from 15 days at the beginning to 5 days toward the end of the season, with an average of 10.4 days for the period. The 14 females deposited 3,962 eggs. The average was 283 eggs, the maximum 390, and the minimum 90 eggs. Male and female longevity averaged 36 and 53.4 days, respectively, and the length of the oviposition period averaged 33.5 days. Apparently the lower temperatures on the soil surface were effective in lengthening the various periods, as indicated, and in increasing the average egg production over the records obtained in other years.

Outdoor oviposition records in 1934 were based on the activities of 13 females which were reared in tile cages and emerged in the period February 14 to March 23.

From a female mated on February 14 first eggs were obtained on March 4. Egg laying continued until April 28. For this series the preoviposition period averaged 11.6 days, the minimum was 5 days, and the maximum 20. The oviposition period ranged from 7 to 35 and averaged 24.2 days.

Individual egg totals decreased considerably over the records obtained in previous years, the average being 142.5 eggs. Other factors than temperature, which showed a close similarity to averages obtained in former years, were apparently responsible for this decrease. Fifty-six percent of the eggs were laid during the first week, which was the highest in this series; also, practically all the eggs were produced during 4 weeks, as compared with 5 weeks in 1932 and 7 weeks in 1933.

The pairs used for oviposition studies were also observed for longevity. The average life period of the males was 25.5 days and of the females 43.5 days.

OVIPOSITION OUTDOORS IN THE SHADE

Five of the eight females confined in the shade of alfalfa and included in the records in table 29 had been reared in salve cans and were taken in copulation on February 26, 1932. The remaining three which were reared in tile cages mated on March 8, 11, and 29, respectively. The length of the preoviposition period ranged from 5 to 14 days and averaged 10.9 days. Egg laying continued over a period of 82 days, from March 8 until May 28, inclusive. Of the 1,552 eggs deposited, 34.5 percent were laid the first week, 28.5 the second, and 17.3 percent more the third week. Individual oviposition records ranged from 95 to 362 and averaged 194 eggs. Because of the favorable temperatures in this location, the oviposition period was lengthened to an average of 35.9 days; and also the adult life, which averaged 28.4 days for the males and 45.9 days for the females, was longer than usual. Oviposition continued over a period of 8 weeks, whereas in the sun it was only 5 weeks.

SUMMARY OF OUTDOOR OVIPOSITION RECORDS

Combining the 3-year records of oviposition outdoors (table 31) it is immediately evident that temperature is the important factor governing the rate of oviposition. This was especially noticeable in 1932, where in the sun deposition continued for 5 weeks, over a period when the temperatures averaged 71.2° F. as compared with 8 weeks in the shade, where the mean was 64.3°. The number of eggs deposited the first week in the shade was also less than in the sun during the different years. Oviposition terminated in the sunny location on May 18, and in the shade on May 28. It is noted that the percentage of eggs deposited during weeks 1 to 5 in the sun did not vary greatly during the 3 years, and that the percentages for the 3-year period corresponded closely to those obtained for the groups of females that were reared and that oviposited in salve cans in the basement. Figure 29 presents graphically the egg-deposition records in the sun and shade locations during weeks 1 to 8, inclusive.

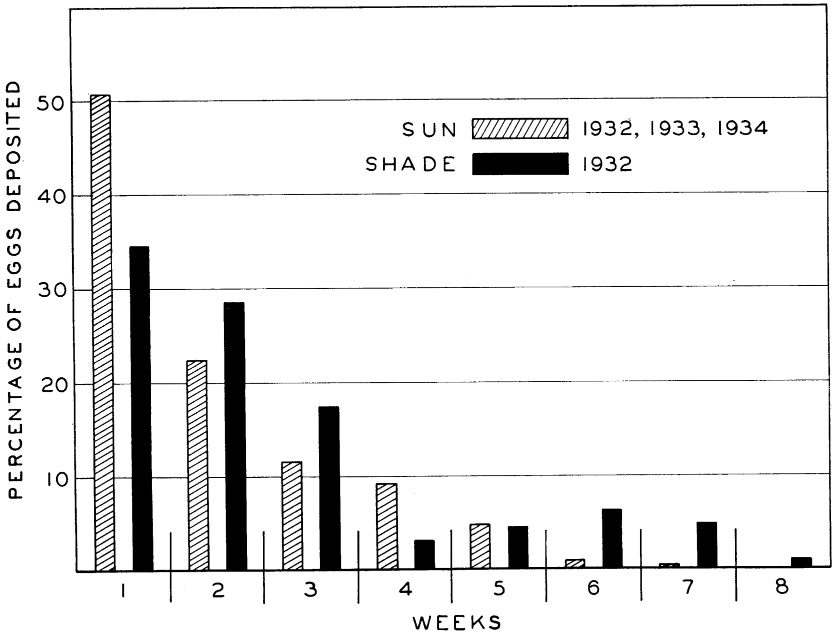

FIGURE 29.—Percentages of eggs deposited weekly by females of the sugar-beet wireworm outdoors in sunny and shaded locations, Alhambra, Calif., 1932–34.

TABLE 31.—*Summary of the numbers and percentages of eggs deposited weekly by adults of the sugar-beet wireworm reared in salve cans and tile cages in sun and shaded locations outdoors, Alhambra, Calif., 1932–34*

Week of oviposition period	Eggs deposited weekly in—									
	1932, by 9 females kept in sun		1933, by 14 females kept in sun		1934, by 13 females kept in sun		1932–34, by 36 females kept in sun		1932, by 8 females kept in shade	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
First	882	52.4	1,877	47.4	1,049	56.6	3,808	50.8	535	34.5
Second	416	24.7	834	21.0	438	23.6	1,688	22.5	443	28.5
Third	169	10.0	451	11.4	246	13.3	866	11.5	269	17.3
Fourth	120	7.1	452	11.4	112	6.0	684	9.1	47	3.0
Fifth	97	5.7	260	6.6	7	.4	364	4.8	72	4.6
Sixth			65	1.6			65	.9	96	6.2
Seventh			22	.6			22	.3	76	4.9
Eighth			1				1		14	.9
Total	1,684		3,962		1,852		7,498		1,552	
Average mean soil-surface temperature	°*F.* 71.2		°*F.* 66.7		°*F.* 68.0				°*F.* 64.3	

OVIPOSITION RECORDS OF ADULTS OF KNOWN AGE

Additional oviposition studies were conducted in 1934, salve-can-reared adults which had completed development after 2, 3, and 4 years being used. The females in the three groups were mated on March 2 and were confined in salve cans without food.

According to the records obtained, little variation occurred in the average number of eggs deposited by the females from larvae completing development in 2 to 4 years, inclusive. The averages ranged from 494.3 for the 2-year-cycle to 551.8 for the 3-year-cycle females, with 539.0 for the 4-year-cycle. It was unfortunate that 1-year-cycle beetles were not available so that the comparison could have included all ages. Being small and less weighty, their total oviposition would undoubtedly be much less than recorded for the older females. The smallest number, 382, were laid by a 2-year-cycle beetle. The average number of eggs deposited by this group of 2-, 3-, and 4-year-cycle adults and the maximum of 704 eggs laid by a 3-year-cycle female were the highest records obtained during the years in which oviposition studies were conducted.

OVIPOSITION AT CONSTANT AND AT BASEMENT TEMPERATURES PRIOR TO TIME OF NORMAL FIELD EMERGENCE

By confining dormant salve-can-reared adults in a constant-temperature cabinet for 1 week at 80° F., two pairs were obtained in copulation on January 16, 1932, 5 weeks before the appearance of the adults in the field and 7 weeks before the first females emerged from tile cages. All the adults appeared very sluggish and displayed little inclination to attempt mating, but another pair was obtained in copulation on January 20, several on January 23, and more throughout February. Attempts to obtain matings previous to these without artificial heating proved unsuccessful.

To determine the effects of various temperatures on the beginning and rate of oviposition, a number of pairs obtained in this manner were confined in constant-temperature cabinets at 80° and 90° F. and in the basement. The results of these studies are shown in table 32.

TABLE 32.—*Oviposition records of salve-can-reared adults of the sugar-beet wireworm in 80° and 90° F. constant temperature cabinets and in the basement prior to time of field emergence, Alhambra, Calif., 1932*

Female No.	Date female mated	Oviposition period: Began	Oviposition period: Ended	Eggs deposited in the specified weeks after oviposition commenced: 1	2	3	4	5	6	7	8	9	10	Total eggs deposited	Eggs obtained by dissection	Potential oviposition	Average mean temperature
				Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	°F
80° F. CONSTANT TEMPERATURE																	
1	Jan. 16	Jan. 20	Feb. 2	182	12									194	0		
4	do	Jan. 27	Feb. 23	17	17	33	28							95	0		
14	Jan. 20	Feb. 6	Mar. 4	141	126	30	13							310	0		
6	Jan. 23	Jan. 27	Feb. 16	141	77	2								220	0		
7	do	do	Feb. 9	105	4									109	0		
8	do	do	Feb. 23	65	90	29	22							206	0		
12	Jan. 26	Feb. 1	Feb. 21	96	2	139								237	0		
17	Feb. 11	Feb. 15	Mar. 13	149	161	129	8							447	0		
18	do	do	Mar. 6	156	173	22								351	0		
19	do	do	Feb. 28	263	77									340	0		
20	do	do	Mar. 6	186	109	96								391	0		
21	do	do	Mar. 13	161	181	9	1							352	0		
22	do	do	do	72	124	158	55							409	0		
24	Feb. 12	Feb. 25	Mar. 2	83										83	0		
23	Feb. 18	Feb. 22	Mar. 6	184	50									234	0		
Total				2,001	1,203	647	127							3,978	0		
Average per female				133.4	80.2	43.1	8.5							265.2			
90° F. CONSTANT TEMPERATURE																	
2	Jan. 19	Jan. 25	Feb. 7	171	125									296	14	310	
9	Jan. 26	Jan. 29	Feb. 18	95	40	4								139	0	139	
10	do	do	Feb. 4	72										72	0	72	
11	do	do	Feb. 11	80	45									125	80	205	
15	Jan. 29	Feb. 8	Feb. 28	95	22	5								122	73	195	
Total				513	232	9								754	167	921	
Average per female				102.6	46.4	1.8								150.8	33.4	184.2	
BASEMENT, RANGE 52–74° F.																	
3	Jan. 23	Jan. 26	Apr. 4	30	11	19	18	43	30	17	12	32	12	224	156	380	64.3
25	Feb. 18	Feb. 27	Mar. 18	173	57	12								242	0	242	65.5
26	Feb. 26	Mar. 5	Mar. 25	146	29	2								177	27	204	66.7
Total				349	97	33	18	43	30	17	12	32	12	643	183	826	
Average per female				116.3	32.3	11	6	14.3	10	5.7	4	10.7	4	214.3	61	275.3	65.5

In the 80° group the first eggs were obtained on January 20 and the last on March 13. Egg deposition extended over a period of from 7 to 28 days, or over an average period of 20.6 days. The preoviposition period ranged from 4 to 17 days and averaged 6 days. An average of 265.2 eggs were deposited, a minimum of 83, and a maximum of 447. Apparently this temperature was favorable for adult activity, as all the females laid their entire quota of eggs, none being obtained by dissection. Of the total eggs deposited, 50.3, 30.2, and 16.3 percent were laid during the first, second, and third weeks, respectively. The first eggs were laid 6 weeks earlier than the normal oviposition in the outdoor cages. The longevity of the males in this group averaged 24 days and of the females 28 days.

The 5 females confined at 90° F. were obtained in copulation between January 19 and 29 and laid eggs during the period January 25 to February 28. Evidently this temperature was less favorable than 80°, as the oviposition period was shortened to an average of 15.4 days, and the preoviposition period to 5 days with an individual variation of from 3 to 10 days. In addition, the lives of the male and female were shortened, averaging 16.6 and 21 days, respectively. The rate of oviposition was hastened, over 68 percent of the eggs being laid during the first week, which was the greatest weekly percentage recorded during these studies, and 30 percent during the second week. Individual egg totals were low, ranging from 72 to 296 and averaging 150.8.

Only 3 pairs were available for obtaining oviposition records at basement temperature. Although meager, these data showed that as a result of the lower temperatures oviposition occurred over a much longer period than was the case at higher temperatures. The average here was 37.3 days as compared with 15.4 days at 90° F. and 20.6 days at 80°. The lives of males and females were also lengthened to 37.6 and 45.6 days, respectively. Apparently the artificial heating tended to stimulate adult activity for several days, as the preoviposition period averaged 7.3 days, which was near the records obtained in the two higher-temperature groups. The percentages of eggs deposited totaled 54.3 and 15.1 during the first and second weeks, respectively, and the average number for the group was 214.3 eggs.

DELAYED OVIPOSITION

Additional studies showed that it was also possible to delay mating and oviposition to nearly 4 months after all normal adult activity had ceased. In this experiment adults which emerged in March 1932 were confined in containers filled with soil and placed in a constant-temperature cabinet held at 40° F. On September 3 these adults were removed to a jar in the basement, where activity was again resumed and several pairs were obtained in copulation. One female deposited 41 eggs before death occurred on September 24. The resulting larvae, normal in all respects, were not given the usual care and died several weeks later.

FECUNDITY

During the 4-year period in which oviposition studies were conducted both in salve cans and in outdoor cages the average number of eggs deposited per female was 268.1 (table 33). The total number of eggs deposited per female during this period ranged from 51 to 704,

the latter number being deposited by a 3-year-old, salve-can reared female in 1934. A summary of the yearly averages shows that 1934 was the most favorable for wireworm reproduction, at least in regard to the number of eggs produced. In this year the average was 360.3 eggs as compared with 308.2 in 1933, 219.5 in 1932, and 186.2 in 1931.

TABLE 33.—*Fecundity of sugar-beet wireworm adults reared in salve cans and tile cages when confined in salve cans in the basement and in oviposition cages outdoors in sun and shaded locations, Alhambra, Calif., 1931–34*

Individuals reared in—	Confined during oviposition period in—	Year	Females	Eggs deposited	Eggs laid per female: Average	Eggs laid per female: Maximum	Eggs laid per female: Minimum
			Number	*Number*	*Number*	*Number*	*Number*
Salve cans	Basement	1931	18	3,441	191.2±11.0	294	89
		1932	11	2,890	262.7±15.9	372	122
		1933	5	2,344	468.8±20.0	543	397
		1934	18	9,319	517.7±13.4	704	382
Total or average			52	17,994	346.0± 7.1	704	89
Tile cages	Basement	1931	10	1,773	177.3± 7.9	233	123
		1932	10	2,214	221.4±19.9	408	65
		1933	13	3,558	273.7± 8.9	359	213
Total or average			33	7,545	228.6± 8.9	408	65
Salve cans and tile cages	Sun	1932	9	1,684	187.1±33.0	559	77
		1933	14	3,962	283.0±13.7	390	90
		1934	13	1,852	142.5±11.5	279	51
Total or average			36	7,498	208.3±11.6	559	51
Salve cans and tile cages	Shade	1932	8	1,552	194.0±21.4	362	95
Grand total or average.			129	34,589	268.1± 5.0	704	51

It is observed that the salve-can-reared females which were larger and heavier deposited on an average more eggs than the small females reared in tile cages. It is believed that the average of 228.6 eggs as obtained for the latter would be the approximate average egg production of adults which as larvae had inhabited soils cropped only a portion of the year, as in sugar-beet and lima-bean fields. Because of the more favorable conditions of soil and food in salve cans, the adults which as larvae were reared therein would, as shown, have a greater average egg-deposition record than females reared in tile cages where soil conditions were less favorable and keen competition for food existed.

Owing to the high temperatures prevailing outdoors in the sun, several of the beetles died before their normal quota of eggs were deposited, this being especially true in 1932. This assisted considerably in lowering the average female egg record for all years outdoors in the sun. The small size of the tile-reared females available for the oviposition studies of 1934 in this location probably accounted for the low average of 142.5. In the shade of alfalfa, where optimum temperatures prevailed, the average was 194 eggs per female.

DURATION OF THE OVIPOSITION PERIOD

In summarizing the oviposition records of females reared in salve cans and of those reared in tile cages during the 3-year period 1931–33, it is observed that the oviposition period for the tile-reared group

averaged 28.5 days, as compared with an average of 36 days for the group reared in salve cans (table 34). Apparently this variation was due to the fact that most of the tile-reared females emerged, mated, and oviposited later in the season when temperatures were much higher. In addition, the high soil temperature which they encountered in their migration surfaceward would undoubtedly also assist in shortening their period of activity. In the two groups the longest oviposition period, 75 days, and the shortest, 8 days, were for salve-can-reared females. In the sun the average ranged from 24.2 days in 1934 to 33.5 days in 1933. The average in the sun for the 3 years was 28, with a maximum of 56 and a minimum of 7 days. For females confined in the shade the duration of the oviposition period averaged 35.9 days, or an increase of 7.9 days over the average obtained in the sun.

TABLE 34.—*Duration of the oviposition period of adults of the sugar-beet wireworm reared in salve-can and tile cages, when confined in oviposition cages in the basement and in sunny and shaded localities outdoors, Alhambra, Calif., 1931–34*

Individuals reared in—	Confined during oviposition period in—	Year	Total records	Oviposition period		
				Average	Maximum	Minimum
			Number	*Days*	*Days*	*Days*
Salve cans	Basement	1931	18	39.0	75	16
		1932	11	25.0	35	8
		1933	5	48.6	63	42
Total or average			34	36.0	75	8
Tile cages	Basement	1931	10	28.9	42	14
		1932	10	26.6	42	14
		1933	13	29.6	49	14
Total or average			33	28.5	49	14
Salve can and tile cages	Sun	1932	9	24.9	35	7
		1933	14	33.5	56	21
		1934	13	24.2	35	7
Total or average			36	28.0	56	7
Salve can and tile cages	Shade	1932	8	35.9	56	21
Grand total or average			111	31.2	75	7

HARDINESS OF THE BEETLES

The beetles are noted for their hardiness and for their ability to withstand excessive handling or unfavorable weather conditions. Very little mortality occurred among the thousands of reared adults that had been carried through the winter in salve cans for use in these studies. Moreover, as shown by the oviposition and longevity records, these adults deposited, on the average, more eggs and remained alive as long as the adults reared in tile cages, that had not been subjected to handling.

Females that had oviposited in overmoist soils in salve cans would occasionally have particles of muddy soil attached to their tarsi, which made movement difficult, but even this did not retard the rate and amount of oviposition.

Of 150 adults that had been removed from their pupal cells in flowerpots and placed in tile cages 6 to 12 inches below the surface on December 5, 1930, 100 emerged in 1931. This showed that the redis-

tribution of adults prior to emergence did not affect the time or rate of their appearance the following season. Emergence in 1931 from the group of cages containing adults that had not been disturbed began on February 24, and the peak was reached on March 11. The disturbed adults emerged and reached their peak on the same dates. This indicates that plowing during the winter months and the subsequent redistribution of the adults in the soil would not likely alter the time and rate of their emergence the following spring. The experiment further demonstrates the hardiness of beetles in being able to withstand unfavorable conditions, such as prevailed after their transfer to the cages, and the ability of the majority to emerge when confined in this manner.

VARIATION IN THE WEIGHT OF ADULTS

It was observed that considerable variation existed in the size of the adults collected in the field or reared at the laboratory. Males and females that had completed development in 1 year were very small, usually only half as large as those which matured after 2 or 3 years. A number of weighings made each season on newly transformed adults showed that the salve-can-reared males that matured in 1 year averaged 28 mg. in weight as compared with 47 and 49 mg. for the 2- and 3-year-old males, respectively. The males reared in tile cages were still smaller, averaging 21 and 25 mg. after 1 and 2 years in the larval stage. A similar variation occurred with the females, except that these were all heavier, increasing from an average of 38 to 82 mg. by the third year, after which no significant increase in weight was noted. Where there is considerable competition for food, as in tile cages, it is natural to expect a lighter weight as compared with adults that as larvae had been confined individually in salve cans. Also, larvae that complete their life cycle in 1 year would be expected to transform to small adults, considering the short duration of their feeding period.

To obtain additional data on the effects of various quantities of food on the weights of larvae and adults, a number of weighings were made of individuals in the rearing series of 1933, consisting of 3 groups fed 10 and 20 kernels of wheat monthly, and 10 kernels monthly except from October 1 to March 1. The larvae were weighed on July 5, 1934, and the same when adults (2-year cycle) shortly after they emerged in September and October of the same year. The results are given in table 35.

TABLE 35.—*Effect of various quantities of food on the length and weight of mature larvae of the sugar-beet wireworm reared in salve cans of the 1933, 2-year-cycle group, and on the weight of the same individuals after emergence as adults, Alhambra, Calif., 1933–34*

Time larvae hatched	Number of records		Larvae [1]				Adults [2]	
			Average length		Average weight		Average weight	
	Males	Females	Males	Females	Males	Females	Males	Females
			Millimeters	*Millimeters*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*
GROUP 1, FED 10 KERNELS OF WHEAT MONTHLY								
Early [3]	5	4	21.6	25.0	61	101	44	78
Intermediate [4]	2	7	21.5	24.0	59	95	47	66
Late [5]	3	7	19.0	24.1	50	101	41	79
Total or average	10	18	20.8	24.3	57	99	44	74
GROUP 2, FED 20 KERNELS OF WHEAT MONTHLY								
Early	4	5	22.2	25.4	66	108	51	81
Intermediate	3	6	20.3	23.3	65	116	48	96
Late	4	6	20.0	24.2	65	104	48	78
Total or average	11	17	20.9	24.2	65	109	49	85
GROUP 3, FED 10 KERNELS OF WHEAT MONTHLY EXCEPT FROM OCT. 1 TO MARCH 1								
Early	3	7	18.0	21.1	49	70	36	63
Intermediate	6	3	18.3	19.7	48	69	45	57
Late	2	8	19.0	20.1	53	64	44	62
Total or average	11	18	18.3	20.4	49	67	42	62
Grand total or average	32	53	20	23	57	91	45	73

[1] Measurements and weighings of larvae made on July 5, 1934.
[2] Adults weighed during September and October 1934.
[3] Apr. 5–10, inclusive, 1933.
[4] Apr. 23–28, inclusive, 1933.
[5] May 20–June 8, inclusive, 1933.

These data show conclusively that the weight of the larvae prior to pupation and that of the adult are governed by the quantity of food accessible during the larval period.

LONGEVITY OF ADULTS

The data on longevity cover only the length of life of adults from time of mating until death, and do not include the undetermined time of adult life spent in the soil from transformation in the summer or fall to emergence, which ranges from 5 to 6 months. Immediately after pairs had mated they were placed either in salve cans and confined in the basement or in oviposition cages which were set up outdoors. The containers were filled two-thirds full with soil that had been run through a 60-mesh screen and which contained approximately 12 percent of moisture by weight. No food was provided in either kind of containers during the life of the adults. The soil was examined and changed daily until the first eggs were obtained and thereafter at weekly intervals until death of the adults.

The length of life of adults varied considerably, depending on the temperature in the location in which the pairs were confined (table 36). Basement temperatures during the seasons of 1931 and 1933 were especially favorable for lengthening their life period, whereas excessively high temperatures in 1932 caused considerable early mortality. The comparison for the tile-cage-reared group was not so striking, but this will be explained later.

TABLE 36.—*Longevity of adults of the sugar-beet wireworm from mating to death, when reared under different conditions, Alhambra, Calif., 1931–34*

Year	Males				Females			
	Records	Longevity			Records	Longevity		
		Average	Maximum	Minimum		Average	Maximum	Minimum
	Number	*Days*	*Days*	*Days*	*Number*	*Days*	*Days*	*Days*
REARED IN SALVE CANS IN BASEMENT								
1931	18	43.1	91	30	18	54.8	81	30
1932	11	25.9	44	6	11	39.7	50	32
1933	5	53.0	68	28	5	63.4	68	52
Total or average	34	39.0	91	6	34	51.2	81	30
REARED IN TILE CAGES OUTDOORS								
1931	10	23.3	38	10	10	43.0	66	33
1932	10	22.0	39	9	10	36.7	48	24
1933	13	23.6	44	9	13	42.8	59	25
Total or average	33	23.0	44	9	33	41.0	66	24
REARED OUTDOORS IN SUN IN SALVE CANS AND TILE CAGES								
1932	9	17.9	39	2	9	39.1	48	21
1933	14	36.0	52	7	14	53.4	66	39
1934	13	25.5	39	12	13	43.5	50	35
Total or average	36	27.7	52	2	36	46.2	66	21
REARED OUTDOORS IN SHADE IN SALVE CANS AND TILE CAGES								
1932	8	28.4	40	6	8	45.9	73	32
Average, 1931 to 1934, inclusive	111	29.8	91	2	111	46.2	81	21

Adults confined outdoors in the sun in 1932 appeared also to have been affected by abnormally high maximum temperatures which prevailed during February and early in March. Males especially were less resistant to the heat, as is shown by the 2-day record, the shortest in all groups during the 3 years. During periods when high temperatures prevail it is natural to expect an adult migration to fields containing cover crops or alfalfa. To determine the longevity of adults seeking such shelter, oviposition cages were set up in an alfalfa plot adjacent to the laboratory, the results of which are shown in table 36.

Most of the adults reared in salve cans were mated in February and early in March, whereas the greater number of the tile-reared adults emerged and were mated from 2 to 3 weeks later and lived during a

period of slightly higher temperatures. In addition, the higher temperature of the soil in the tile cages, especially near or on the surface, which the adults would encounter as they migrated upward or after they had reached the surface, would assist in shortening the life of tile-reared adults.

SEASONAL HISTORY

The seasonal history (fig. 30) varies from year to year according to the temperature in the different localities and the type of soil. In the more sandy soils, which respond quickly to temperature changes, emergence of males has occurred as early as February 5, followed by females on February 13. In the heavier soils males have appeared

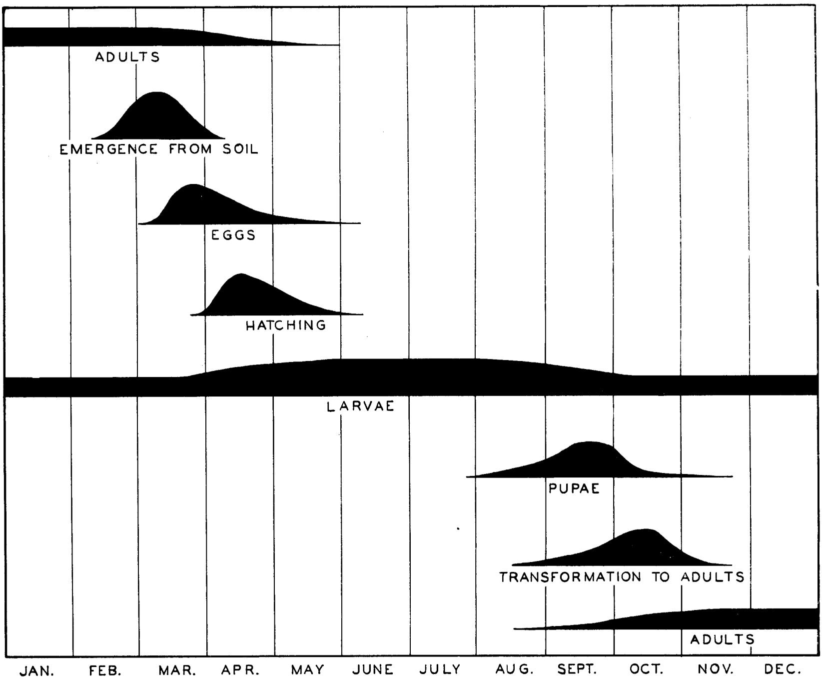

FIGURE 30.—Seasonal history of *Limonius californicus* in southern California.

on February 20 and females on March 1. The peak of emergence in the field generally occurred between March 16 and 31 and in the tile cages between March 5 and 19. Emergence in the cages terminated on April 4. Mating usually takes place immediately after issuance from the soil

In the laboratory basement egg laying began on February 17 and in outdoor cages in the sun on March 3. The peak of oviposition occurred between March 15 and 31 and terminated on May 18 in the sun, and on May 28 in the shade. Hatching continued over a period of 78 days, from March 23 until June 8.

A few of the earlier-hatched larvae completed development the same season and the majority matured the second year, but some of the individuals under observation required 3, 4, or 5 years. Outdoors in tile cages the percentage maturing the first year was considerably

higher than with those reared in the laboratory basement, with a correspondingly lower percentage of second- and third-year individuals.

The first pupa was recovered on July 22 and the last on October 27, the peak occurring during the period from September 16 to 22. Newly transformed adults were obtained from August 12 until November 21. If not disturbed by cultural practices, the adults remain in their pupal cells until December. During this month movement surfaceward begins, with the males slightly in advance of the females.

NATURAL CONTROL

Graf (*4*) lists numerous birds as enemies of adults of the sugar-beet wireworm. Among these the California shrike (*Lanius ludovicianus gambeli*) was found to be the most important. The carabid *Calosoma cancellatum* Esch. was especially valuable in destroying the beetles that had accumulated under old beets for protection. Frequently several of these carabids, with the remains of *Limonius californicus* adults, would be found underneath malva traps used in trapping the adults. A number of these carabids were placed separately in battery jars and supplied with a surplus of elaterid beetles. Over a period of 50 days between March 26 and May 14, 1934, the number of wireworm adults destroyed daily ranged from an individual average of 2.6 to 4, with a minimum of 1 and a maximum of 19. The greatest number of wireworm adults killed was 202 per battery jar, and the least 130. These same predators also destroyed an average of 20 host larvae per day per battery jar. These larvae had been introduced near the end of the emergence period when beetles were scarce. Graf (*4*) also found this species with the remains of injured wireworms in the field. The carabids were observed in the field throughout the entire emergence period.

Reared adults were frequently found attacked by fungus but none of the thousands collected in the field appeared to be affected. Heavy rains are of little value as a controlling factor. Adults that had been trapped under malva placed in shallow pits were drenched by a 2-inch rainstorm over a 24-hour period, but these appeared normal and very active when examined on the following day.

The larvae, being inaccessible and, in addition, heavily chitinized, seemed to be entirely free from attacks by internal parasites. Both Graf (*4*) and the workers at Alhambra, Calif., have examined thousands of larvae without finding a single parasitized individual. Along the sea coast gulls and crows followed the plows in large numbers, apparently feeding on the wireworms brought to the surface.

Fungi and bacteria destroyed a small number of the larvae and pupae confined in salve cans, but they were never observed on field-collected material. Eggs were frequently attacked by fungi in salve cans, especially when the latter and the soil had not been sterilized. The bacteria or fungi were not identified. Larvae confined in flower-pots and in tile cages were often found heavily infested with mites (family Tyroglyphidae), but these appeared not to have affected the larvae in the least, as they fed and molted normally.

Probably the most valuable predacious enemies of the sugar-beet wireworm are the larvae of *Psilocephala frontalis* Cole (dipterous family Therevidae). These predators are long, slender, and whitish and, being soil inhabiting, they are frequently mistaken for wire-

worms. They pierce the heavily chitinized integument, usually near the middle, and suck the body juices. Ten therevid larvae collected in the field between May 18 and 27, 1931, were confined individually with wireworms in salve cans. Together they destroyed 33 wireworms between May 18 and the time the individuals began pupating on June 1. Twenty-one therevids collected in the field on March 16, 1933, killed 70 mature larvae of *Limonius californicus* over a period of 50 days. One individual killed 9 wireworms. The therevids used in these studies were almost mature when collected. Judging from the number of wireworms killed during the short time the therevids were under observation, they are undoubtedly responsible for the death of a large number of wireworms in the field over their entire larval period. Further investigations are being conducted on the habits and biology of this insect.

SUMMARY

The sugar-beet wireworm is distributed throughout the irrigated areas of all the Pacific Coast States and causes severe injury to sugar beets, lima beans, potatoes, and many other vegetable crops. Damage to most of the affected crops is caused by the feeding of the larvae on the germinating seed or on the young plant. Wireworm injury to potato tubers often causes them to be classified in a lower grade. Seed potatoes may be burrowed into or injured by the larvae to such an extent as to necessitate replanting.

Injury to crops may begin early in February and continue throughout the spring, and even during the summer in fields under irrigation. With a decline in soil temperatures in the fall, larval activity is resumed, with resultant damage to crops as late as into October.

Dissemination of this species is mainly by flight. Winds may assist in carrying the adults considerable distances.

In moist top soil 50 percent of the eggs were laid in the first inch, whereas when the surface soil was low in moisture most of the eggs were laid between the 2½- and 4-inch levels.

The incubation period for eggs deposited in February averaged 35.1 days, for March-deposited eggs 32.2 days, for April-deposited eggs 30.7 days, and for eggs deposited in May, 27.2 days. The range of the incubation period was from 23 days for eggs deposited in May to 46 days for eggs deposited in February. Eggs hatched over a period of 77 days, from March 23 until June 8.

The duration of the larval period in salve cans averaged 171.1, 502.8, 857.8, 1,233.8, and 1,589.7 days for those maturing in 1, 2, 3, 4, and 5 years, respectively. Males had a slightly shorter larval period than the females.

A constant temperature of 80° F. accelerated larval development and caused irregular pupation, whereas at a constant temperature of 70° development and pupation were in accord with the rearings conducted at basement temperature.

There was no difference in the rate of development of sugar-beet wireworms fed lima beans, corn, or wheat. A group of larvae existed on a monthly diet of 1 kernel of wheat for a period of 4 years. When a portion of these larvae were fed 8 kernels of wheat in the spring, all pupated by fall, whereas in the group continued on 1 kernel per month a few pupations occurred, but the majority continued as larvae into the next year.

No significant relation existed between the length of larvae and the time of pupation, nor can the length of larvae be used in estimating their age.

Larvae 3, 4, and 5 months old consumed, on an average, more food during the months of July, August, and September than at any other time of their life period. Although small, they apparently are responsible for a large share of the damage inflicted to fall-planted vegetable crops.

The number of instars ranged from 10 to 13 for wireworms supplied with an abundance of food and completing development in 2 years under favorable cage conditions. Under adverse cage conditions, 1 larva died after completing 22 molts in the course of a 5-year cycle. During the first year of larval life activity was greatest and the duration of the instars shortest. With less activity during the winter and in the following year, the average duration of the instars was increased.

Of larvae reared in salve cans and fed various kinds and quantities of food, 4.1 percent matured in the first year, 80.7 percent in the second, 13.8 percent in the third, 1.2 percent in the fourth, and 0.2 percent in the fifth. In outdoor cages 4.5 percent matured in a 1-year cycle, 13.7 percent in a 2-year cycle, and 0.7 percent in a 3-year cycle. A total of 81.1 percent of the larvae reared in outdoor cages were either the victims of cannibalism or died from natural causes or injuries received when handled. More of the early-hatched larvae matured the first year than of the late-hatched, in both salve cans and outdoor cages.

The prepupal period averaged 7.6 days. Females remained in the prepupal stage for an average of 8.6 days and males 7.4 days. The earliest pupation in salve cans occurred on June 13, in 1934, and the last pupation on October 27, in 1931 and 1933. The seasonal peak ranged in different years between September 1 and 22. The pupal period ranged from a minimum of 13 days to a maximum of 34, and averaged 21.4. In outdoor cages the average depth of pupation was 10.5 inches, the minimum depth 4, and the maximum 24.

Emergence of adults in the field was observed as early as January 25 in Los Angeles County and February 1 in Orange County. The peak of emergence, based on sweepings of alfalfa, occurred in the period March 16 to 31.

If not disturbed by cultural practices, the adults remained until December in their pupal cells in the soil at an average depth of 10.5 inches. During December a movement surfaceward began, and by January 31, adults were found at an average depth of 7.5 inches. On February 20 they were found at an average depth of 4 inches. In this movement upward males precede the females by several inches, thus accounting for their earlier appearance in the field and in outdoor cages.

The beginning of adult emergence is governed by the soil temperatures during December and January. Low temperatures delayed the appearance of the adults to March 1, whereas high temperatures caused the earliest emergence (January 25). Although the peak of emergence each year varies with the temperature, all such peaks occurred during the period from February 27 to March 19. Males were always more numerous during the first portion of the emergence period. Adult emergence during all the years when the observations reported in this bulletin were under way terminated April 2, 3, or 4.

The proportion of females increased with the length of the larval life, from 7.1, 48.7, 59.4 and 66.7, to 100 percent for individuals reared in salve cans and completing development in 1, 2, 3, 4, and 5 years, respectively. For those reared in outdoor cages, and completing development in 1, 2, and 3 years, the percentages of females were 32.2, 55.5, and 60, respectively.

The duration of the preoviposition period outdoors averaged 11 days. In the basement the average for females reared in salve cans was 5.2 days and for outdoor-cage-reared females 6.1 days.

Females reared in salve cans and outdoor cages and confined in the basement after emergence deposited 57, 20.8, and 10.6 percent, or a total of 88.4 percent, of their eggs in the first, second, and third weeks, respectively, after oviposition began. Outdoors in the sun, the percentages of eggs deposited were 50.8, 22.5, and 11.5 respectively, or a total of 84.8 percent for the first 3 consecutive weeks.

Dormant adults reared in salve cans and exposed to a constant temperature of 80° F. for 1 week mated and laid eggs 6 weeks previous to normal oviposition in outdoor cages. Adults emerging during March and held at a constant temperature of 40° mated immediately when removed on September 3, and deposited fertile eggs.

In the basement the earliest egg deposition was on February 17 and in outdoor cages in the sun on March 3. Oviposition terminated on May 18 in the sun and on May 28 in the shade. The average number of eggs laid was 268.1, and the maximum of 704 eggs was laid by a 3-year-cycle female reared in a salve-can cage. Adults reared in outdoor cages averaged 228.6 eggs as compared with 346 eggs for females reared in salve cans. Outdoors in the sun the average number of eggs laid was 208.3.

The average oviposition period in the basement for females reared in outdoor cages was 28.5 days and for females reared in salve cans 36 days. In oviposition cages in the sun 28 days was the average and in the shade 35.9 days. The average for all years was 31.2 days, the maximum 75, and the minimum 7 days.

Male longevity averaged 29.8 days and female longevity 46.2. The maxima were 91 days for a male and 81 for a female. Adults reared in salve-can cages lived longer than those reared in outdoor cages.

Listed as important enemies of the sugar-beet wireworm are *Calosoma* beetles, birds, fungi, bacteria, and dipterous larvae of the family Therevidae.

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U. S. GOVERNMENT PRINTING OFFICE: 1941